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COMPARISON OF THE NITRIFYING POWERS OF SOME HUMID AND SOME ARID SOILS [1]

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INTRODUCTION

It will be remembered by those who are interested in the subject under consideration that Stewart (11)[2] took occasion in 1912 to question the correctness of the view then prevalent, due principally to the high authority of Hilgard (3, p. 68), that nitrification proceeds with great intensity in arid soils. It will also be remembered that in the statement above cited and in subsequent papers (12, 13) Stewart controverted the theory of Headden (1, 2) with respect to the cause of unusually large nitrate accumulations in certain Colorado soils on similar grounds. The evidence presented for the latter controversion consisted of numerous analyses of irrigated and unirrigated soils at the Utah Agricultural Experiment Station and of soil and soil-forming material of the Book Cliff areas in Utah and Colorado. The analyses represented the quantity of nitrogen in the form of nitrates or the quantities of other "alkali" salts, or both, in the various soils and soil-forming materials at the time the sampling was done. As a result of his studies of these data, Stewart concluded that the intense power of nitrification attributed to arid soils, because of the large amounts of nitrates present in the field, is nonexistent, that it may actually be feeble as compared with that of humid soils, and that the large quantities of nitrates found as noted can be more readily and plausibly explained on the basis of accumulation by water movement from adjacent soil or soil-forming materials rich in salts (including nitrates). The latter contention is supported by numerous analyses of the large variety of soils, sandstones, and shales

[1] The samples of soil from the different States were sent us by the chemists or agronomists of the several Stations, and acknowledgment in addition to that already made is here publicly expressed. We owe and express our sincere thanks also to Prof. C. F. Shaw, in charge of the soil-survey work of the California Agricultural Experiment Station, for allowing us a portion of every soil sample collected in the soil-survey areas which have already been mapped in this State.

[2] Reference is made by number to "Literature cited," p. 82.

involved, which indicate that an increase in the nitrate content of soils, such as those described by Headden (1, 2) in Colorado, is always accompanied by an increase in the quantity of the other alkali salts. Not only on the basis of his own data obtained as above but also on those of Headden himself, Stewart was able to make out a strong case in support of his explanation anent the origin of the heretofore-mysterious "niter-spots."

It will be noted that both Hilgard and Stewart employed actually or by implication an indirect method for arriving at their conclusions. While Stewart's method was less indirect in that seasonal variations in nitrate accumulations were studied, thus allowing something like a measurement of the soil's nitrifying power in the field, it can at best be productive only of results which call for further investigation. In other words, the determination of nitrates in field soils, no matter how frequently made, as a basis for determining the power of the soil to nitrify any nitrifiable material, is subject to more objections because of a lack of control of conditions than is a direct, if arbitrary, method of determining the nitrifying power of a soil in the laboratory. In an attempt, therefore, to obtain data by a more direct method, which might serve to reveal the truth about the nitrifying powers of humid and arid soils, the writers have carried out a series of studies the results of which form the principal topic of this paper.

PLAN, MATERIAL, AND METHODS OF EXPERIMENTS

In the experiments the plan was to compare under controlled and uniform conditions in the laboratory the nitrifying powers of a large number of representative soils from both humid and arid regions. In seeking for a scheme to use as the basis for the selection of such soils, it occurred to the senior author that it could be arranged by employing one soil type at least from every State in the Union to compare with a large number of California soils collected in connection with the soil-survey work of the State. Fortunately, there had just been completed a collection of soils from all the States and Territories in the Union (at least one soil and one subsoil from each State or Territory) and the writers were therefore supplied with what might be regarded as representative soil material. For the illustration of arid soils the samples collected to represent the different types of four soil-survey areas in California were employed. Approximately 45 humid were compared with 150 arid soils.

The nitrifying power of each soil was determined, using the nitrogen in the soil, in sulphate of ammonia, in dried blood, and in cottonseed meal for every soil. The last-named was employed in 100-gm. portions in tumblers, as in the methods now common among soil bacteriologists. The soils containing as nearly as possible optimum amounts of water were

incubated for one month at 28° to 30° C. The usual devices were employed for preventing an undue evaporation of moisture, the maintenance of a uniform water supply, and for mixing soil with fertilizer materials. The soil nitrogen was, of course, employed as naturally occurring in the 100-gm. soil portions, sulphate of ammonia (in solution) was employed at the rate of 0.2 per cent, dried blood at the rate of 1 per cent, and cottonseed meal at the rate of 1 per cent, all based on the air-dry weight of the soil. The phenoldisulphonic-acid method for determining nitrates, as described by Lipman and Sharp (8), was employed throughout the experiments, except as otherwise stated. The nitrate content of the original soil was subtracted in all cases, and calculations were made of the absolute amounts of nitrates produced, of the total nitrogen present (whether soil nitrogen alone or soil nitrogen plus fertilizer nitrogen), and of the percentage of the latter which was transformed in a month's incubation period into nitrates. For the purposes of the last-named determination only the complete whole numbers for the percentage concerned were computed, a plus sign being used after every one to indicate that the exact percentage was less than 1 per cent in excess of the number given.

Throughout these experiments the writers have been cognizant of the weaknesses which obtain in any method yet devised to obtain results in the laboratory with soil-bacterial activities which are directly translatable into terms of field conditions and magnitudes. For example, the fact that uniform moisture and such exceptional air conditions as are present in a constant-temperature incubator are not to be found in the field has not been overlooked. Nor yet have the writers assumed that the large amounts of fertilizer employed by them in the experiments exercise the same effect as the much smaller quantities employed in farm practice. There has been employed as a basis what seems to be the reasonable hypothesis that soils and fertilizers, particularly the former, bearing a certain relationship to one another as regards nitrifying power in the laboratory, should bear approximately the same relationship to one another in the field. This should be particularly so as regards results obtained with the soil's own nitrogen.

Further, the writers also realize two other serious difficulties which beset the investigator engaged on problems such as the one in hand. Seasonal variations in the nitrifying powers of soils are of great magnitude. This has been demonstrated by numerous investigators. Not the least disquieting data on that subject are in the hands of the writers, representing the most extensive study yet carried out on seasonal variations in the ammonifying and nitrifying powers of soils. The other difficulty is that the soils which are compared with arid soils were collected in most of the States on Experiment Station lands, which are not truly representative of average conditions obtaining among

humid soils. A minor objection which has been urged may also be mentioned here—namely, that of a given lot of soil collected at the same time two 100-gm. samples may give widely different nitrifying powers. It may be observed here that the writers have never been able to substantiate such a claim. They have merely called attention to some of the most important and perhaps the only important objections in the path of validating such comparative studies and other similar ones. It will be noted that scarcely any comment has been made regarding the objections and difficulties in question. Occasion will be taken to examine them critically and evaluate their importance in a more proper place. It may be said that in these experiments the attempt has been made to obtain relative and not absolute values, and despite the accompanying weaknesses of the methods, it is believed that current ideas with respect to the intensity of nitrification in the soils of humid and of arid regions have been improved and rendered more definite.

EXPERIMENTS WITH "FOREIGN"[1] SOILS

The word "foreign" is applied in this paper to soils coming from other States than California, unless specifically qualified in some other manner. While subsoils were available in every case and were studied in the foreign soils and while several soil types were available from some States, only one such type of surface soil and the results obtained therewith will be discussed. The results obtained with the foreign soils, arranged as above described, follow in Table I, which gives the results of nitrification of the soil, sulphate of ammonia, dried blood, and cotton-seed-meal nitrogen.

TABLE I.—*Comparison of the nitrification in soils from various States*[a]

State.	Soil type.	Soil nitrogen (Group I).			Soil nitrogen and sulphate of ammonia (Group II).			Soil nitrogen and dried blood (Group III).			Soil nitrogen and cotton-seed meal. (Group IV).		
		Nitrate nitrogen produced.	Total soil nitrogen present.	Nitrogen in soil nitrified.	Nitrate produced.	Total nitrogen present.	Nitrogen nitrified.	Nitrate produced.	Total nitrogen present.	Nitrogen nitrified.	Nitrate produced.	Total nitrogen present.	Nitrogen nitrified.
		Mg.	*Mgm.*	*Per ct.*	*Mg.*	*Mgm.*	*Per ct.*	*Mg.*	*Mgm.*	*Per cent.*	*Mg.*	*Mgm.*	*Per ct.*
Alabama	Norfolk sandy loam.	9.20	23.60	38+	1.50	63.60	2+	0.10	155.60	Tr.	4.10	73.60	5+
Alaska	Rich peat	.....	225.20	.....	1.10	265.20	Tr.	81.10	357.20	22+	25.10	272.20	9+
Arizona	Fine sandy loam (Alkali).	.....	46.00	.....	.....	86.00	.....	.....	178.00	.....	.....	93.00	.....
Arkansas	Huntington clay loam.	13.80	68.40	20+	5.40	108.40	4+	7.80	200.40	3+	13.30	115.40	11+
Colorado	Silt loam	7.50	108.30	6+	17.50	148.30	11+	29.50	240.30	12+	19.50	155.30	12+
Connecticut	Gloucester fine sandy loam.	5.60	209.80	2+	7.00	249.80	2+	9.00	341.80	2+	18.00	256.80	7+
Delaware	Sassafras loam	54.75	109.00	50+	34.75	149.00	23+	66.75	241.00	27+	54.75	156.00	35+
Florida	Calcareous peat (Everglades).	54.00	1894.00	3+	32.00	1934.00	1+	52.00	2026.00	2+	42.00	1941.00	2+

[1] This term was borrowed from Sackett (10).

[a] Does not include Hawaii, Porto Rico, or California.

TABLE I.—*Comparison of the nitrification in soils from various States*—Continued.

State.	Soil type.	Soil nitrogen (Group I).			Soil nitrogen and sulphate of ammonia (Group II).			Soil nitrogen and dried blood (Group III).			Soil nitrogen and cotton-seed meal (Group IV).		
		Nitrate nitrogen produced.	Total soil nitrogen present.	Nitrogen in soil nitrified.	Nitrate produced.	Total nitrogen present.	Nitrogen nitrified.	Nitrate produced.	Total nitrogen present.	Nitrogen nitrified.	Nitrate produced.	Total nitrogen present.	Nitrogen nitrified.
		Mg.	*Mgm.*	*Per ct.*	*Mg.*	*Mgm.*	*Per ct.*	*Mg.*	*Mgm.*	*Per cent.*	*Mg.*	*Mgm.*	*Per ct.*
Georgia	Cecil loam	9.85	27.80	35+	6.85	67.80	10+	2.85	159.80	1+	11.85	74.80	15+
Guam		18.80	177.60	10+	28.80	217.60	13+	35.80	309.60	11+	30.80	224.60	13+
Idaho	Silt loam	12.05	152.40	7+	5.25	192.40	2+	25.25	284.40	8+	18.25	199.40	9+
Illinois	Marshall silt loam	32.00	219.60	14+	4.00	259.60	1+	27.00	351.60	8+	15.00	266.60	5+
Indiana	Miami silt loam	8.42	111.80	7+	15.42	151.80	10+	33.42	243.80	13+	20.42	158.80	12+
Iowa	Wisconsin drift	17.40	146.80	11+	3.50	186.80	1+	61.50	278.80	22+	14.50	193.80	7+
Kansas	Oswego silt loam	24.30	177.60	13+	6.10	217.60	2+	30.50	309.60	9+	17.50	224.60	7+
Kentucky	Lexington limestone soil.	4.15	149.60	2+	.95	189.60	Tr.	23.95	281.60	8+	11.95	196.60	6+
Louisiana	Orangeburg sandy loam.	4.35	64.20	6+	.75	104.20	Tr.	.55	186.20	Tr.	21.95	111.20	19+
Maine	Aroostook loam	16.05	148.20	10+	11.25	188.20	5+	31.25	280.20	11+	20.25	195.20	10+
Maryland	Sassafras clay loam.	15.98	72.60	22+	7.38	112.60	6+	18.78	204.60	9+	10.78	119.60	9+
Massachusetts	Podunk fine sandy loam.	7.88	151.00	5+	12.88	191.00	6+	17.88	283.00	6+	19.88	198.00	10+
Michigan	Miami sandy loam.	17.40	112.5	15+	6.40	152.5	4+	31.40	244.50	12+	14.40	159.50	9+
Minnesota	Fargo clay loam	37.00	316.20	11+	20.00	356.20	5+	53.00	448.20	11+	18.00	363.20	4+
Mississippi	Loam	7.70	34.80	22+	4.70	74.80	6+	—.30	166.80	.....	4.70	81.80	5+
Missouri	Upland silt loam	10.15	89.40	11+	5.75	129.40	4+	26.75	221.40	12+	14.75	136.40	10+
Montana	Yakima silt loam	18.00	218.20	8+	11.50	258.20	4+	35.50	350.20	10+	18.50	265.20	6+
Nebraska	Fine sandy loam	39.30	76.80	51+	14.30	116.80	12+	.30	20.80	Trace.	20.30	123.80	16+
Nevada	Clay loam	15.00	67.00	22+	4.00	107.00	3+	22.00	199.00	11+	17.00	114.00	14+
New Hampshire	Boulder clay	13.57	211.20	6+	5.57	251.20	2+	18.57	343.20	5+	9.97	258.20	3+
New Jersey	Sassafras loam	5.68	83.80	6+	.68	123.80	Tr.	13.68	215.80	6+	11.68	130.80	8+
New Mexico	Anthony fine sandy loam.	15.00	39.00	38+	12.00	79.00	15+	—1.00	171.00	.....	9.00	86.00	10+
New York	Dunkirk clay loam.	24.85	160.80	15+	16.85	200.80	8+	39.85	392.80	14+	22.85	207.80	10+
North Carolina	Cecil sandy loam	12.52	40.40	30+	2.87	80.40	3+	19.87	172.40	11+	14.87	87.40	17+
North Dakota	Clay loam	6.20	279.80	3+	12.00	319.80	3+	42.00	411.80	10+	17.00	326.80	5+
Ohio	Wooster silt loam	23.70	120.20	19+	3.70	160.20	2+	26.70	252.20	10+	14.70	167.20	8+
Oklahoma	Loam	6.75	82.40	8+	2.75	122.40	2+	12.75	214.40	5+	11.75	129.40	9+
Oregon	Willamette Valley sandy loam.	13.20	935.00	1+	47.20	975.00	4+	57.20	1067.00	5+	50.20	982.00	5+
Pennsylvania	Hagerstown silt loam.	19.00	127.20	14+	7.00	167.20	4+	26.00	259.20	10+	17.00	174.20	9+
Rhode Island	Miami silt loam	8.55	163.60	5+	3.25	203.60	1+	19.25	295.60	6++	12.25	210.60	5+
South Carolina	Cecil sandy loam	13.20	43.20	30+	11.00	83.20	12+	—.20	175.20	.....	19.00	90.20	21+
South Dakota	Clay loam	19.60	193.00	10+	13.60	233.00	5+	29.60	325.00	9+	22.60	240.00	9+
Tennessee	Upland loam	11.06	102.00	10+	4.26	142.00	3	21.86	234.00	9+	14.86	149.00	9+
Texas	Black adobe	15.40	103.40	14+	24.40	143.40	17+	49.40	235.40	20+	19.40	150.40	12+
Utah	Greenville loam	22.90	128.60	17+	28.90	168.60	17+	48.90	260.60	18+	24.90	175.60	14+
Vermont	Sandy loam	8.80	85.20	10+	2.80	125.20	2+	25.80	217.20	11+	14.80	132.20	11+
Virginia	Hagerstown loam	15.20	95.00	16+	6.00	135.00	4+	27.00	227.00	11+	18.00	142.00	12+
Washington	Shot clay	6.60	41.80	15+	2.60	87.80	2+	35.80	173.80	20+	9.00	94.80	9+
West Virginia	Meigs sandy loam	7.84	184.60	4+	1.44	224.60	Tr.	9.84	316.60	3+	6.04	231.60	2+
Wisconsin	Carrington sandy loam.	16.50	174.80	9+	11.50	214.80	5+	28.50	306.80	9+	22.50	221.80	10+
Wyoming	Loam	15.15	99.20	15+	24.15	139.20	17+	57.15	231.20	24+	27.15	146.20	18+

Before discussing nitrification proper it is of importance to note the conditions which obtain in the foreign soils with respect to total nitrogen content. This consideration is important because it emphasizes what has been only vaguely appreciated in the past—namely, the great discrepancy between the nitrogen content of humid and of arid soils. Moreover, it is important because the soil's total nitrogen content may have a bearing on the absolute quantities of nitrates produced through the

agency of nitrification. Out of 49 foreign soils, about 9 of which should be reckoned as arid rather than humid, 30, or about 61 per cent of the whole number, contain more than 0.1 per cent of total nitrogen (only in very small part, including nitrates). If allowances are made for the arid or semiarid soils among the foreign soils, about three-quarters of the soils from the humid region are found to contain more than 0.1 per cent of nitrogen. Only 8 soils, or about 14 per cent of the total of 49, contain less than 0.05 per cent of nitrogen each, and 4 of these belong properly to the arid or semiarid class. Only 2 soils contain less than 0.03 per cent total nitrogen, but neither of these is an arid soil. These figures are very interesting and worth remembering for comparison later with similar statistics anent the California soils. The second column of figures in Group I of Table I can be made to show percentages of total nitrogen by moving the decimal point three places to the left.

With respect to the absolute quantities of nitrate produced, only 16 out of 47 soils tested produced from their own nitrogen less than 10 mgm. of nitrate nitrogen, and only 2 of them produced less than 5 mgm. of nitrate nitrogen in the same period. No relationship whatever is discernible between the total amount of nitrogen present in the soil and the amount which was rendered into nitrate. About two-thirds of the soils tested were therefore able to produce in every case more than 10 mgm. of nitrate nitrogen in a month's incubation period. Likewise, nearly two-thirds of the soils tested rendered more than 10 per cent of the nitrogen present in the soil into nitrate, and several more approached the 10 per cent mark very closely. Moreover, nearly 40 per cent of the soils tested transformed in every case more than 15 per cent of the total nitrogen present into nitrate. If the few characteristically arid or semiarid soils among the foreign soils are disregarded, less than 35 per cent of the soils would fall in the class last named. It is also of great interest to note that over 12 per cent of the soils tested transformed more than 30 per cent of the nitrogen in them into nitrate under the circumstances noted; and two of the soils, the Delaware and Nebraska samples, transformed into nitrate more than 50 per cent of the nitrogen which they contain. It may be purely a matter of coincidental interest but possibly worthy of note that of the 9 soils which transformed between 20+ per cent and 38+ per cent of their nitrogen into nitrate, thus placing them in a class next to the two very exceptional soils just referred to, 7 belong to the Southern or South Atlantic group of States, and the other 2 are from New Mexico and Nevada, which more properly belong with the arid or semiarid group.

The results obtained when sulphate of ammonia is added to the soil nitrogen and the whole incubated are found to be opposite to that taken by the data for soil nitrogen. The addition of sulphate of ammonia to the foreign soil has not induced, as might be expected, an increase in the production of nitrate over that produced from the soil's nitrogen alone,

but has, on the contrary, caused a reduction in the soil's power to render nitrogen into nitrate. This holds, of course, only in general, and several exceptions may be found to the rule. If the absolute amounts of nitrate produced as given in Group II of Table I are compared specifically with those given in Group I, it will be found that all the soils tested except six—namely, those from Indiana, Oregon, Texas, Utah, Wyoming, and Guam—produced far less nitrate when sulphate of ammonia was added to them than they did from their own nitrogen alone. It will be noted that of the six soils which did produce more nitrate under the conditions noted than from their own nitrogen only one is a soil belonging strictly to the humid region. The effects of sulphate of ammonia on the nitrification of soil nitrogen in humid soils is very striking and difficult to explain. The acidity of soils appears to be inadequate to explain the situation.

As is to be expected, smaller absolute transformations of nitrogen into nitrate in soil and ammonium sulphate than in soil nitrogen mean a smaller percentage transformation of the total nitrogen present. Hence, whereas in the case of the soil nitrogen alone, 11 soils out of 47, or 23 per cent, transformed more than 20 per cent of nitrogen in every case into nitrate, only one soil belongs in that class when the series containing soil nitrogen plus sulphate of ammonia nitrogen is considered. Also, whereas nearly 66 per cent of the soils in the soil-nitrogen group transform in every case more than 10 per cent of the total nitrogen into nitrate, only about 23 per cent of the same soils in the ammonium-sulphate group fall in that category. These limited statistical illustrations on the differences obtaining between the experimental series resulting in the soil-nitrogen group and the ammonium-sulphate group are sufficiently emphatic to need no further comment at this point.

Group I of Table I is compared with Group III, which sets forth the results of the dried-blood series with the foreign soils, only 10 soils out of 47 or 48, or about 20 per cent, will be found which produced less nitrate when blood (1 per cent) was added to them than when only their own nitrogen supply was allowed to nitrify. Again, attention is called to what is probably a purely coincidental but interesting circumstance like the one above mentioned. Just as 9 of the soils which transformed more than 20 per cent and less than 39 per cent of their own nitrogen into nitrate included 7 which came from States of the Southern or South Atlantic group, so in this case of the 10 soils which produced less nitrate from dried-blood nitrogen plus the soil nitrogen than from the latter alone, 7 belong to the group of States which are in nearly all cases the same. Of the three other soils, two are from the semiarid region—namely, Nebraska and New Mexico—and only one is from the northern portion of the humid region—namely, Illinois. It is worthy of note that in all but the Florida and Illinois soil, of the group of 10 just considered, the nitrogen content is below 0.08 per cent, and in most of them is below 0.05 per cent.

The amounts of nitrate produced are smaller in Group III of Table I than in Group I for reasons which are obvious and which have been referred to previously. Nevertheless, in spite of the disadvantage which the added dried-blood nitrogen creates in this series with respect to the relative considerations, about 23 soils, or nearly 50 per cent of the whole number, transform more than 10 per cent of the total soil plus dried-blood nitrogen into nitrate, and several other soils approach that record closely. In five cases more than 20 per cent of the total nitrogen present is transformed into nitrate. Taken as a whole, therefore, and in spite of the large quantities of blood used, the foreign soils must be adjudged efficient nitrifiers of dried-blood nitrogen. This is particularly to be kept in mind for comparison with data from the California soils.

Group IV of Table I, which gives the results obtained in the cottonseed-meal series, is not strikingly different from Group III, which represents the dried-blood series. Nevertheless some distinct points of dissimilarity between the two require some comment. Thus, it must be noted that in the dried-blood series, 34 out of 48 soils produced more nitrate nitrogen than they did with the soil nitrogen alone. In the cottonseed-meal series only 26 out of the same total of soils accomplished that task. On the other hand, certain soils which induced only losses of nitrate nitrogen with dried blood, like the Georgia, Louisiana, and South Carolina soils, gave with cottonseed meal increases of nitrate over those produced with the soil nitrogen alone.

The percentage of total nitrogen which is transformed into nitrate in the cottonseed-meal series with the foreign soils is not strikingly unlike that of the dried-blood series when the soils are regarded as a whole. Nevertheless the individual soils show marked differences in the direction noted. Thus, for example, eight of the soils in the dried-blood series transform nothing or less than 2 per cent of the total nitrogen present into nitrate, whereas in the cottonseed-meal series no soil is productive of no nitrate, and only two fall in the 2 per cent class, or thereabouts. In other words, it would appear that while the dried blood is better suited to the foreign soils if a few soils are eliminated from consideration, cottonseed meal is better suited to the average soil, provided the influence of the amount of fertilizer used is disregarded. In general, it would appear that dried blood is a more readily and more efficiently nitrifiable material for the soils of the humid region than cottonseed meal.

In a general survey of the results obtained with the foreign soils, it seems to be true beyond question that with respect to relative quantities of nitrates produced from the different forms of nitrogen, the soil nitrogen is the most efficiently nitrified of the four forms tried. Sulphate of ammonia is the least efficiently nitrified, while dried blood and cottonseed meal differ very little. Table II summarizes the situation with respect to one degree of nitrate formation only.

TABLE II.—*Total nitrogen present transformed into nitrate in foreign soils*

Nitrifiable material.	Soils transforming 10 per cent or more of total nitrogen into nitrate.
	Per cent.
Soil nitrogen alone	68
Soil nitrogen plus ammonium sulphate	23
Soil nitrogen plus dried blood	47
Soil nitrogen plus cottonseed meal	45

Based on the absolute criterion of the production of 20 mgm. of nitrate nitrogen, or more, under the circumstances noted, sulphate of ammonia still remains the lowest in the scale with only 8 soils possessing such a record, the soil nitrogen is next with 9 soils in that class, cottonseed-meal nitrogen is next with 13 such soils, and dried-blood nitrogen stands best, with 31 such soils. The corresponding figures obtained when the production of 15 mgm. of nitrate is taken as a criterion are as follows: Soil nitrogen, 23 soils; ammonium-sulphate nitrogen, 11 soils; dried-blood nitrogen, 36 soils; and cottonseed-meal nitrogen, 28 soils.

In brief, therefore, dried-blood nitrogen takes first place for the absolute amount of nitrate produced therefrom by the foreign soils, cottonseed-meal nitrogen being second, soil nitrogen third, and ammonium-sulphate nitrogen last. On the relative basis, however, the dried-blood nitrogen goes from first to second place, and the soil nitrogen from third to first place, with the sulphate of ammonia remaining last, and the cottonseed meal third in order.

EXPERIMENTS WITH CALIFORNIA SOILS

In order to make the choice of California soils representative not only of the arid region but also of parts of the State with widely varying climatic and other conditions, soil types were chosen from two central to northwest soil-survey areas and from two southern California areas. These areas were the Ukiah and the Bay areas and the Riverside and the Pasadena areas. The rainfall for the first two areas varies from 20 to 40 inches or more a year, depending on the location; and nearly all of it falls during the winter. The precipitation for the Riverside and Pasadena areas varies from 7 to 12 inches or more, also limited almost entirely to the winter months. The nitrification tests were arranged as described above and in the same way as those of the foreign soils. The first area to be considered here is the Bay area, and Table III sets forth the results obtained with the soil types of that area and with the different forms of nitrogen.

TABLE III.—*Nitrification in types from the Bay area series*

Soil type.	Soil nitrogen (Group I).			Soil nitrogen and sulphate of ammonia (Group II).			Soil nitrogen and dried blood (Group III).			Soil nitrogen and cottonseed meal (Group IV).		
	Nitrate produced.	Total nitrogen in soil.	Nitrogen nitrified.	Nitrate produced.	Total nitrogen in soil.	Nitrogen nitrified.	Nitrate produced.	Total nitrogen in soil.	Nitrogen nitrified.	Nitrate produced.	Total nitrogen in soil.	Nitrogen nitrified.
	Mgm.	*Mgm.*	*P. ct.*	*Mgm.*	*Mgm.*	*P. ct.*	*Mgm.*	*Mgm.*	*P. ct.*	*Mgm.*	*Mgm.*	*P. ct.*
Tidal marsh clay	0.10	137.20	Tr.	2.00	177.20	1+	1.50	269.20	Tr.	5.00	184.20	2+
Altamont heavy loam	2.35	112.00	2+	7.75	152.00	5+	14.75	244.00	6+	9.75	159.00	6+
Yolo silty clay loam	1.20	93.80	1+	.80	133.80	Tr.	.60	225.80	Tr.	.45	140.80	Tr.
Dublin clay adobe	1.50	65.80	2+	4.00	105.80	3+	4.00	197.80	2+	6.00	112.80	5+
Dune sand	.80	35.00	2+	.72	75.00	Tr.	.....	167.00	.....	1.20	82.00	1+
Oakley light sandy loam	3.00	51.80	5+	4.00	91.80	4+	−1.00	183.80	.....	3.50	98.80	3+
Altamont clay adobe	.30	50.40	Tr.	.40	90.40	Tr.	.....	182.40	.....	.....	97.40	.....
Diablo clay adobe	2.00	65.80	3+	12.00	105.80	1+	7.80	197.80	3+	8.00	112.80	7+
Residual clay adobe	3.00	116.20	2+	3.00	156.20	1+	3.00	248.20	1+	2.50	163.20	1+
Santa Rosa loam	.90	86.80	1+	4.50	126.80	3+	9.50	218.80	4+	7.50	133.80	5+
Altamont light types	3.00	72.80	4+	3.00	112.80	2+	.....	204.80	.....	7.00	119.80	5+
No. 150 Brown type heavy loam	5.50	183.40	2+	20.90	223.40	9+	18.50	315.40	5+	11.50	230.40	4+
Tuscan stony loam	.43	32.20	1+	.43	72.20	Tr.	2.13	164.20	1+	.63	79.20	Tr.
Do	1.40	138.60	1+	5.30	178.60	2+	4.80	270.60	1+	4.30	185.60	2+
Santa Rosa loam	1.57	61.60	2+	1.28	101.60	1+	−.12	193.60	.....	.48	108.60	Tr.
No. 150 Gray phase loams	1.80	82.60	2+	1.80	122.60	1+	.60	214.60	Tr.	5.10	129.60	3+
Newark loam	4.10	75.60	5+	4.30	115.60	3+	25.90	207.60	12+	6.10	122.60	4+
Antioch loams and clay loams	4.36	72.80	5+	6.56	112.80	5+	15.96	204.80	7+	16.96	119.80	14+
No. 12 black phase	1.60	99.40	1+	6.40	139.40	4+	12.00	231.40	5+	7.60	146.40	5+
Auburn clay loam	.80	32.20	2+	.50	72.20	Tr.	1.00	164.20	Tr.	.10	79.20	Tr.
Corning loam	.95	44.80	2+	9.50	84.80	11+	−.55	176.80	.....	3.45	91.80	3+
Pleasanton	4.00	64.40	6+	2.80	104.40	2+	.30	196.40	Tr.	20.00	111.40	17+
Montezuma clay loam	.20	32.20	Tr.	.30	72.20	Tr.	.....	166.20	.....	.....	79.20	.....
Montezuma clay adobe	2.20	86.80	2+	8.20	126.80	6+	25.20	218.80	11+	16.20	133.80	12+
Yolo clay	3.70	113.40	3+	8.10	153.40	5+	.10	245.40	.....	1.20	160.40	Tr.
Yolo light type silt loam	4.00	131.60	3+	18.20	171.60	10+	19.20	263.60	7+	23.20	178.60	12+
Corning loam	2.44	58.80	4+	2.54	98.80	2+	−.06	190.80	.....	5.94	105.80	5+
Yolo gravelly loam	2.18	82.60	2+	4.68	122.60	3+	33.68	214.60	15+	23.68	129.60	18+
Antioch loam	.50	64.40	Tr.	.50	104.40	Tr.	.....	196.40	.....	.40	111.40	Tr.
Antioch light sandy loam	2.84	105.00	2+	14.04	145.00	9+	12.04	237.00	5+	21.04	152.00	13+

BAY AREA SOILS

The figures for total nitrogen in the second column of Table III show that only 8 soils out of 30, or approximately 26 per cent, contain more than 0.1 per cent of nitrogen, and that only one of them contains more than 0.14 per cent of nitrogen. In other words, the foreign soils contain relatively 2½ times as many soils which contain nitrogen in excess of 0.1 per cent as do the soils of the Bay area; and, moreover, many of the first-named group contain very much more nitrogen than 0.15 per cent. The effects of the arid climate are therefore quite evident on soils of the Bay area and are only emphasized by comparison with the foreign soils existing under a humid climate. It must be further remarked that the comparison gains in significance from the reflection that while the Bay area soils are subjected to a long season of drought, they receive annually between 20 and 30 inches of rainfall, depending on the part of the area concerned, and are in addition protected from excessive oxidation influences by much fog and cool weather. In respect to the number of soils

in the Bay area containing less than 0.05 per cent of total nitrogen, the last-named group of soils is not unlike the foreign group. The soils of the latter contain 14 per cent of such soils as against 16 per cent for the Bay area. No soil in the Bay area contains less than 0.023 per cent of total nitrogen.

After a study of one form of nitrogen at a time and in the same order as before, a striking difference is found between the absolute quantities of nitrates produced by the soils of the Bay area out of their own nitrogen and those produced by the foreign soils under similar circumstances. Thus, for example, only 1 soil out of 30 in the Bay area produces a little more than 5 mgm. of nitrate nitrogen, and all other soils produce less. If this observation is compared with the corresponding one for the foreign soils of the humid region, the feeble nature of the nitrifying power of the soils of the Bay area for their own nitrogen is very noticeable, as is the very vigorous power in that direction possessed by the foreign soils. In the latter only 2 soils out of a total of 47 produced less than 5 mgm. of nitrate nitrogen, while in the former only 1 soil produced more than 5 mgm. of nitrate nitrogen. The absolute magnitude of nitrate production in soils of the Bay area varies from 0.1 mgm. to 5.50 mgm., thus making a very small range. Again, there is evidence in Table III that the magnitude of nitrifying power for soil nitrogen is independent of the total amount of nitrogen present. Thus, for example, the largest production of nitrate occurs in the soil with the highest total nitrogen content in the whole series. On the other hand, the lowest nitrate production occurs in the soil with the third highest quantity of total nitrogen.

It follows from what has been said in the preceding paragraph that only small percentages of the nitrogen present in the soils of the Bay area could have been transformed into nitrate. The best record made consists in a conversion by the Pleasanton soil of over 6 per cent of the total nitrogen present into nitrates. In three other soils 5 per cent of the nitrogen was thus converted, and in the other 26 soils the records are much poorer. Comparing the relative data of Table III with those set forth in Table I, section 1, one can not help being struck by the remarkably high nitrifying efficiency of the foreign soils as compared with that of the Bay area soils.

The use of sulphate of ammonia as a nitrifiable material with the Bay area soils shows also the relatively low nitrifying power of the latter. Nevertheless Table III, Group II, brings out a very important fact—that is, that in the case of the absolute amounts of nitrate produced the Bay area soils gave increases over the amount of nitrate produced from the soil alone in all but 5 out of a total of 30 soils. This is a diametrically opposite effect to that induced by sulphate of ammonia in the foreign soils. On a relative basis the results in the sulphate-of-ammonia

series were superior to those in the soil-nitrogen series as is shown clearly in Table III, Group II, whereas in Table III, Group I, the highest percentage of nitrogen transformed into nitrate was slightly in excess of 6. The corresponding figure for Group II is 11, and several other soils, besides, approach that record. In general, it would seem that sulphate of ammonia stimulates nitrification in soils of the Bay area, while it depresses nitrification in the foreign soils.

With dried blood the Bay area soils show a loss in nitrate production over that of which the soil is capable on its own nitrogen supply in over 43 per cent of the soil types, so far as absolute quantities of nitrates are concerned. In a number of these cases, moreover, there is not only less nitrate produced than from soil nitrogen alone, but the soil's original nitrate supply is lost besides. On the other hand, there are about 9 soils in the Bay area series which, on the basis of production of nitrate in the absolute sense, surpass any in the series with soil nitrogen alone, and, similarly, all but one in the sulphate-of-ammonia series. It may be noted, however, that none of these soils consists of coarse, sandy material with a small absorbent surface, and none contains less than 0.073 per cent of total nitrogen, nearly all of them containing considerably more than 0.08 per cent. It is the last group of 9 soils showing naturally a number of good results on the relative basis in Table III, Group III, which reveals the highest percentage transformation of total nitrogen into nitrate yet noted with the Bay area soils in these experiments. The record is a 15 per cent transformation in the case of the Yolo gravelly loam. One transformation of 12 per cent and one of 11 per cent are also noted, but all the rest are considerably below those figures. In general, it would seem that the heavier soils and such as are better supplied with nitrogen than the average of the Bay area series will give better results with dried blood than with sulphate of ammonia or soil nitrogen, but the rest (more than two-thirds of the total number) will not do as well with dried blood as with the other forms of nitrogen.

Considering the cottonseed-meal results in the case of the Bay area soils, as set forth in Table III, Group IV, from the absolute amounts of nitrate produced cottonseed meal is to be regarded as of less value than dried blood from some points of view and of more value from others. To be more specific, no soil produces as much nitrate from cottonseed meal as does the Yolo gravelly loam from dried blood. On the other hand, there are less soils in the cottonseed-meal series than in the dried-blood series which are induced to lose in nitrifying power by the incorporation of the fertilizer and none at all which lose part or all of the nitrate nitrogen originally contained in them. Relatively, the cottonseed-meal series is ahead of all others with the Bay area soils in that the largest amount of nitrogen transformed into nitrate is there noted. This record is attained by the same soil as that having the record in the dried-blood series and amounts to an 18 per cent transformation of the total nitrogen present into nitrate. The Pleasanton

soil accomplishes a 17 per cent transformation in this series, and three other soils transform more than 12 per cent of the nitrogen present into nitrate. The other soils are considerably inferior in the direction noted.

PASADENA AREA SOILS

The soil types of the Pasadena area number 33, and data are here given either for the whole number or for one or two less, in accordance with the circumstances attending the experimental work. Table IV sets forth the results obtained with the Pasadena area soils with the different forms of nitrogen as above described.

TABLE IV.—*Nitrification in Pasadena area soil type*

Name of type.	Soil nitrogen (Group I).			Soil nitrogen and sulphate of ammonia (Group II).			Soil nitrogen and dried blood (Group III).			Soil nitrogen and cotton-seed meal (Group IV).		
	Nitrate produced.	Total nitrogen present in soil.	Nitrogen nitrified.	Nitrate produced.	Total nitrogen present in soil.	Nitrogen nitrified.	Nitrate produced.	Total nitrogen present in soil.	Nitrogen nitrified.	Nitrate produced.	Total nitrogen present in soil.	Nitrogen nitrified.
	Mgm.	*Mgm*	*P. ct.*	*Mgm.*	*Mgm.*	*P. ct.*	*Mgm.*	*Mgm.*	*P. ct.*	*Mgm*	*Mgm.*	*P. ct.*
Dublin clay adobe	7.60	109.20	6+	39.60	149.20	26+	2.60	241.20	1+	50.60	156.20	32+
Diablo clay	5.68	54.60	10+	15.88	94.60	16+	− .32	186.60	.....	7.68	101.60	7+
Zelzah light loam	20.30	77.00	26+	8.80	117.00	7+	− .20	209.00	.....	5.80	124.00	4+
Altamont clay	9.80	154.00	6+	47.80	194.00	24+	39.80	286.00	13+	27.80	201.00	13+
Zelzah gravelly loam	9.44	61.60	15+	15.44	101.60	15+	− .56	193.60	.....	20.44	108.60	18+
Holland loam	17.93	67.20	26+	7.93	107.20	7+	− .08	199.20	.....	27.93	114.20	24+
Hanford coarse sandy loam	4.28	54.60	7+	9.38	94.60	9+	− .13	186.60	.....	.68	101.60	Trace
Hanford gravelly sandy loam	5.59	68.60	8+	17.19	108.60	15+	− .81	200.60	.....	− .81	115.60	.....
Hanford sandy loam	3.70	40.60	9+	5.90	80.60	7+	− .30	172.60	.....	3.90	87.60	4+
Hanford fine sandy loam	.....	.....	.....	15.57	.....	.....	− .43	.....	.....	13.58	.....	.....
Hanford loam	.....	100.80	.....	14.79	140.80	10+	9.79	232.80	4+	39.79	147.80	26+
Tejunga stony sand	4.00	18.20	21+	2.80	58.20	4+	.....	150.20	.....	.....	65.20	.....
Zelzah stony loam	6.00	64.40	9+	7.00	104.40	6+	.....	196.40	.....	24.00	111.40	21+
Hanford stony loam	3.88	28.00	13+	6.28	68.00	9+	− .13	160.00	.....	− .13	75.00	.....
Placentia loam	5.50	68.60	8+	3.00	108.60	2+	− 1.50	170.60	.....	28.50	115.60	24+
Holland sandy loam	5.39	46.20	11+	3.39	86.20	3+	− .61	178.20	.....	5.39	93.20	5+
Hanford stony sandy loam	3.80	67.20	5+	9.30	107.20	8+	− 2.20	199.20	.....	11.80	114.20	10+
Antioch clay loam	8.00	182.00	4+	38.00	222.00	17+	122.00	314.00	38+	36.00	229.00	15+
Chino silty clay loam	14.40	151.20	9+	42.40	191.20	22+	79.40	283.20	27+	30.40	198.20	15+
Chino clay adobe	11.00	382.20	2+	61.00	422.20	14+	119.00	514.20	23+	33.00	429.20	7+
Chino loam	− 9.00	187.60	.....	10.00	227.60	4+	36.00	319.60	11+	68.00	234.60	28+
Hanford fine sandy loam	13.20	88.20	14+	45.20	128.20	35+	8.70	220.20	3+	77.20	135.20	57+
Chino silty clay loam	7.00	219.80	3+	55.00	259.80	21+	81.00	351.80	23+	31.00	266.80	11+
Hanford fine sand	1.20	35.00	3+	4.20	75.00	5+	− 1.80	167.00	.....	10.20	82.00	12+
Tejunga sand	3.80	15.40	24+	2.80	55.40	5+	− .20	147.40	.....	− .20	62.40	.....
Yolo loam	− 2.00	123.20	.....	13.60	163.20	8+	42.00	255.20	16+	8.30	170.20	4+
Dublin clay loam	7.80	105.00	7+	11.80	145.00	8+	19.80	237.00	8+	75.80	152.00	49+
Dublin clay	9.95	131.60	7+	64.95	171.60	37+	47.95	263.60	18+	31.95	178.60	17+
Hanford sand	4.10	25.20	16+	3.80	65.20	5+	.....	157.20	.....	.20	72.20	Trace
Zelzah clay loam	9.00	109.20	8+	21.00	149.20	14+	3.00	241.20	1+	53.00	156.20	33+
Altamont loam	7.67	74.20	10+	14.67	114.20	12+	17.70	206.20	8+	23.67	121.20	19+
Diablo clay adobe	7.95	100.80	7+	16.15	140.80	11+	35.95	232.80	15+	19.95	147.80	13+
Altamont clay loam	.50	93.80	Trace	13.00	133.80	9+	17.00	225.80	7+	13.80	140.80	9+

The Pasadena area contains a larger percentage of soils having more than 0.1 per cent of nitrogen than does the Bay area. In the latter, for example, 26 per cent of the soils contained more than 0.1 per cent of nitrogen, while in the former more than 40 per cent of the soils belong in that class. Nevertheless it must still be observed that even the

Pasadena area falls short, approximately by 21 per cent, of having as large a number of soils with more than 0.1 per cent of nitrogen as the foreign-soil group. While, therefore, the soils of the Pasadena area approach more closely in nitrogen content those of the foreign group than do the soils of the Bay area, they are still distinctly inferior to the foreign soils. The effect of aridity of climate therefore makes itself plainly manifest in the Pasadena as it does in the Bay area series. It must be further remarked, however, that again owing to climatic conditions, a larger number of soils with less than 0.05 per cent of nitrogen are found in the Pasadena area than in the Bay area, and more of that class than among the foreign soils. The percentage of such is greater than 21 in the Pasadena area, as against 16 for the Bay area, and 14 for the foreign soils. Two soils out of the thirty-three in the Pasadena area contain less than 0.02 per cent of nitrogen, and two others contain less than 0.03 per cent of nitrogen.

On the basis of the absolute values for the nitrate from the soil nitrogen (Table IV, Group I) it would seem that the Pasadena area soils, though manifestly superior in nitrifying power as a class to the Bay area soils, are still far from being equal in that direction to the foreign soils. Thus, for example, 85 per cent of the soils in the Pasadena area produced less than 10 mgm. of nitrate nitrogen in 100 gm. of soil under the circumstances described, while the foreign soils numbered only 27 per cent of such soils among them. It is therefore very clear that so far as absolute quantities of nitrate produced are concerned even the fertile Pasadena area soils are inferior transformers when compared with foreign soils. On the other hand, when compared with the Bay area soils on the basis of a 5-mgm. production of nitrate, the Pasadena soils are clearly superior. Thus, among the latter there are 20 soils of the class last mentioned, whereas among the Bay area there is but 1 such soil.

On the relative basis, or that the criterion of which is percentage of soil nitrogen transformed into nitrate, the Pasadena area soils make even a better showing than on the absolute basis when compared with the Bay area soils. Likewise, they are less inferior when so judged in comparison with the foreign soils for obvious reasons concerned with the total nitrogen content. Thus 4 soils out of 33 (12 per cent) in the Pasadena area transforms more than 20 per cent of their total nitrogen content into nitrate as against 11 out of 44 soils of that class, or 25 per cent, in the case of the foreign soils. The highest individual record for percentage nitrogen transformation is attained equally by the Zelzah light loam and the Holland loam, which transform more than 26 per cent of the total nitrogen present into nitrate. This, while very high, is below the record attained by several of the foreign soils. All of these considerations, moreover, must be viewed in conjunction with the fact that even the group of foreign soils contains a few arid or semi-arid soils similar to the California soils which are being studied here.

Some very interesting data are available in Table IV, Group II, which gives the results with sulphate of ammonia. Thus, only about 21 per cent of the soils in the Pasadena area produced less nitrate from the sulphate of ammonia nitrogen plus the soil nitrogen than from the latter alone. It is interesting to note that the percentage of such soils is so nearly the same in the two arid-soil series thus far considered, even though the latter are in other respects very different. To emphasize again the wide difference existing in respect to the sulphate-of-ammonia nitrogen between the humid (as illustrated by the foreign) and the arid soils, one need but recall that 88 per cent of the humid soils failed to respond to sulphate of ammonia, whereas only 20 per cent of the arid soils behaved in that manner.

As other points of interest in Table IV, Group II, may be mentioned the following: (1) Only four soils in the whole series transform less than 5 per cent of the total nitrogen present into nitrates. (2) Six soils of the series transform more than 20 per cent of the total nitrogen present into nitrates. (3) In one soil, the Dublin clay, over 37 per cent of the total nitrogen present is nitrified, and another soil, the Hanford fine sandy loam, approaches closely to that record. (4) Both soils, the Zelzah light loam and the Holland loam, which have the highest record on the relative basis in Table IV, Group I (soil nitrogen alone), lose in nitrifying power very markedly when sulphate of ammonia is added to them, while the Dublin clay and the Hanford fine sandy loam, which do only moderately well with soil nitrogen alone, make the highest records, as above indicated, with soil nitrogen plus sulphate-of-ammonia nitrogen. (5) It should be noted that in the sulphate-of-ammonia series no soil loses its original nitrate content without replacing and adding to it by nitrification. A loss of the soil's original nitrate content does, however, occur in the case of two soils, the Chino loam and the Yolo loam, in the series with soil nitrogen alone. All of these points, moreover, are of great interest in comparison with the results for the Bay area soil series as obtained by the use of sulphate of ammonia. In general, of course, the superiority at nitrification of the soils in the Pasadena series to that of the Bay area series is more emphasized in Table IV, Group II, than heretofore.

In the experiments with dried blood in the case of the Pasadena area soils (see Table IV, Group III), results totally different in nature from those obtained with sulphate of ammonia are noted. Thus, 63 per cent of all the soils tested produce less nitrate under the circumstances above described when dried blood plus the soil nitrogen are available for nitrification than when only the soil nitrogen is present. This is 20 per cent in excess of the number of such soils in the Bay area, despite the fact that the latter area contains less soils than the Pasadena area with a percentage of nitrogen higher than 0.1. Again, however, as in the case of the Bay area, several of the soils produce in absolute quantities much

more nitrate than is produced by any of the same series when either soil nitrogen alone is present or when it is present with sulphate of ammonia. The number of such soils is about the same in the Pasadena as in the Bay area series, and in no one of them does the nitrogen content go quite as low as 0.1 per cent. They are, besides, soils of large internal surface throughout. Of the two other soils, which, in addition to the ones just mentioned, produce more nitrate in the blood series than in either of the foregoing, both are of large internal surface, and one contains very nearly 0.1 per cent of nitrogen, while the other contains nearly 0.075 per cent of nitrogen.

While on the absolute basis in the dried-blood series the Pasadena and Bay area soils are much alike, with the former in some respects superior and in other respects inferior to the latter, the difference is more marked on the relative basis. Thus, the records made for a percentage transformation of nitrogen into nitrate attain higher values in the Pasadena area than in the Bay area soils, and four soils of those above noted transform more than 20 per cent of the nitrogen present into nitrate, while three others pass the 15 per cent mark. It will be seen that there is only one soil in the Bay area even in the latter class in the dried-blood series. The foreign soils behave as a class of humid soils in a diametrically opposite manner from the Pasadena area soils with respect to dried blood. For the most emphatic proof of this, the reader can compare this paragraph with that discussing Table I, Group III.

Cottonseed meal gives in many respects results similar in the Pasadena area soils to those obtained with it in the Bay area soils, though in one or two respects the two are very different. Thus, for example, 26 per cent of the Bay area soils produce less nitrate from soil nitrogen plus cottonseed-meal nitrogen than from the former alone. The corresponding figure for the Pasadena area soils is 21 per cent. It is also interesting to observe that the last-named value is exactly or very nearly that of the analogous figure for the sulphate-of-ammonia series in the two soil areas above compared. Most striking of all are the very high absolute and almost necessarily high relative amounts of nitrates produced by many of the Pasadena area soils in the cottonseed-meal series. Thus, while there are among the foreign soils but two which transform more than 20 per cent of the total nitrogen in the soil and cottonseed meal into nitrate and none such in the Bay area soils, there are nine, or 28 per cent, of such soils in the Pasadena area group. Moreover, four of these nine transform, as indicated, more than 30 per cent of the nitrogen into nitrate, and one of these reaches the very high figure of a 57 per cent transformation. That cottonseed meal can be more readily and efficiently nitrified in the Pasadena soils as a class than it can in the foreign and the Bay area groups of soils is patent. Since, however, the Pasadena soils are under the most arid conditions of the three and

the Bay area soils are the intermediate group in that respect, it appears that cottonseed meal is better suited to arid than to humid soils. It may be well to note here that in the different groups of soils thus far studied the percentages of soils producing less nitrate from cottonseed meal plus soil nitrogen than from the latter alone are as follows: Foreign soils, 37 per cent; Bay area, 26 per cent; and Pasadena area, 21 per cent. The first figure is doubtless too low, because the foreign soils include several arid and semiarid soils which were not separated for purposes of this calculation.

RIVERSIDE AREA SOILS

Only 3 out of 52 soils of the Riverside area contain as much as 0.1 per cent of nitrogen, or more. That is equivalent to something over 5 per cent of the total number of soils and is strikingly low when contrasted with 66 per cent of such soils for the foreign soils, 40 per cent for the Pasadena area, and 26 per cent for the Bay area. What is even more striking is that including the three soils just mentioned there are but 8 soils (15 per cent) in the Riverside area which contain as much or more than 0.05 per cent of nitrogen. Over 36 per cent, or more than one-third of all the soils in this area, contain less than 0.03 per cent nitrogen. Two soils contain less than 0.01 per cent nitrogen and four others less than 0.015 per cent of nitrogen. Of the four groups of soils thus far studied, including the Riverside area, this last is clearly one in which the total nitrogen content is distinctly below that of all other groups. From the discussion already given this subject, such a circumstance should not be unexpected, since the general tendency is for more arid climates to produce soils with a lower nitrogen content than that of soils in a humid climate.

When the situation is reviewed with respect to nitrate formation from the soil-nitrogen supply in the Riverside areas (see Table V), some further interesting data become evident. In the first place it is plain that the absolute amounts of nitrate formed are very small and, while of a slightly greater magnitude than those of the Bay area, are still of about the same order. No soil in the whole area produces, under the conditions noted, as much as 10 mgm. of nitrate nitrogen, the largest amount produced being 7.40 mgm., produced by the Montezuma silty clay loam. Moreover, there are but 13 out of 53 soils, or about 24 per cent, which produce as much or more than 5 mgm. of nitrate nitrogen under the same conditions. There are, thus, more than three-fourths of the total number of soils tested in the Riverside area which produce less than 5 mgm. of nitrate nitrogen, and most of them form from 1 to 3 mgm. only. Here again, as in the case of the Bay area soils and the others, it appears impossible to find evidence for establishing a definite relation between

total nitrogen present and nitrate produced. Thus, for example, in the Riverside area, as in the Bay area, the largest amount of nitrate formed from the soil nitrogen is found in the soil with the highest total nitrogen content, but no nitrates are produced by the soil with the third highest total nitrogen content.

TABLE V.—*Nitrification in Riverside area soil types*

Name of type.	Soil nitrogen (Group I).			Soil nitrogen and sulphate of ammonia (Group II).			Soil nitrogen and dried blood (Group III).			Soil nitrogen and cottonseed meal (Group IV).		
	Nitrate produced	Total nitrogen present in soil.	Nitrogen nitrified.	Nitrate produced	Total nitrogen present in soil.	Nitrogen nitrified.	Nitrate produced	Total nitrogen present in soil.	Nitrogen nitrified.	Nitrate produced	Total nitrogen present in soil.	Nitrogen nitrified.
	Mgm.	*Mgm.*	*P. ct.*	*Mgm.*	*Mgm.*	*P. ct.*	*Mgm.*	*Mgm.*	*P. ct.*	*Mgm.*	*Mgm.*	*P. ct.*
San Joaquin sandy loam	1.80	32.20	5+	1.50	72.20	2+	−1.00	164.20	.....	10.00	79.20	12+
Placentia loam	5.80	42.00	13+	15.30	82.00	18+	47.90	174.00	27+	21.90	89.00	24+
Zelzah sandy loam	4.00	26.60	15+	40.00	66.60	60+	.....	158.60	.....	32.00	73.60	43+
Tejunga fine sandy loam	5.20	47.60	10+	47.20	87.60	53+	95.20	179.60	53+	50.40	94.60	53+
Sierra loam	.60	15.40	3+	1.50	55.40	2+	.....	147.40	.....	3.00	62.40	4+
Placentia sandy loam	5.18	22.40	23+	6.07	62.40	9+	−.12	154.40	.....	11.88	69.40	17+
Tejunga fine sand	3.92	28.00	7+	63.92	68.00	9+	−.08	160.00	.....	14.92	75.00	19+
Zelzah loam	3.74	32.20	11+	9.74	72.20	13+	8.54	164.20	5+	15.74	79.20	19+
Zelzah clay loam	3.40	53.20	6+	13.90	93.20	14+	32.10	185.20	17+	15.90	100.20	15+
Holland sandy loam	2.80	29.40	9+	5.00	69.40	7+	.....	161.40	.....	12.80	76.40	16+
Hanford loam	2.80	28.00	10+	6.40	68.00	9+	6.00	160.00	3+	20.00	75.00	26+
Hanford clay loam	6.80	74.20	9+	23.40	114.20	20+	63.60	206.20	30+	38.40	121.20	31+
Sierra loam	1.90	32.20	5+	4.80	72.20	6+	23.80	164.20	14+	11.80	79.20	14+
Hanford sandy loam	5.96	28.00	21+	9.36	68.00	13+	−.04	160.00	.....	6.96	75.00	9+
Hanford fine sandy loam	5.35	33.60	15+	15.75	73.60	21+	5.75	165.60	3+	31.75	80.60	39+
Hanford gravelly sandy loam	1.40	36.40	3+	17.40	76.40	22+	−.60	168.40	.....	27.40	83.40	32+
Hanford stony gravelly sandy loam	3.80	44.80	8+	12.60	84.80	14+	.....	176.80	.....	17.50	91.80	19+
Hanford loam	5.60	49.00	11+	27.60	89.00	31+	33.60	181.00	18+	63.60	96.00	66+
Hanford stony sand	2.35	5.60	41+	1.15	45.60	2+	−.05	137.60	.....	.95	52.60	1+
Hanford sandy loam	4.05	43.40	9+	8.85	83.40	10+	38.85	175.40	22+	27.85	90.40	30+
Tejunga sand	3.00	14.00	21+	1.90	54.00	3+	.....	146.00	.....	3.00	61.00	4+
Tejunga gravelly sand	1.52	11.12	13+	19.93	51.12	38+	−.08	143.12	.....	4.22	58.12	7+
Hanford sand	5.60	21.00	26+	.80	61.00	1+	.60	153.00	Tr.	2.80	68.00	4+
Hanford gravelly sand	4.10	37.80	10+	4.10	77.80	5+	−1.50	169.80	.....	15.20	84.00	18+
San Joaquin loam	2.00	35.00	5+	14.00	75.00	18+	1.60	167.00	Tr.	25.40	82.00	30+
Tejunga sandy loam	3.20	33.60	9+	7.20	73.60	9+	8.40	165.60	5+	15.20	80.60	18+
Hanford fine sandy loam	4.00	28.00	14+	12.00	68.00	17+	.90	160.00	Tr.	16.00	75.00	21+
Hanford gravelly loam	4.92	47.60	10+	7.92	87.60	9+	1.42	179.60	Tr.	13.92	94.60	14+
Placentia gravelly loam	5.00	36.40	13+	2.00	76.40	2+	.90	168.40	Tr.	.40	83.40	Tr.
Hanford stony loam	.....	110.60	.....	15.70	150.60	10+	47.40	242.60	19+	17.40	157.60	11+
Hanford coarse sandy loam	3.10	37.80	8+	4.00	77.80	5+	2.40	169.80	1+	24.00	84.80	28+
Montezuma loam	6.20	161.00	3+	44.00	201.00	21+	49.60	293.00	16+	32.50	208.00	15+
Montezuma clay adobe	4.45	33.60	13+	5.95	73.60	8+	2.15	168.60	1+	3.35	80.60	4+
Hanford coarse sand	1.35	15.40	8+	.45	55.40	Tr.	−.05	286.00	.....	.45	62.40	Tr.
Pedley fine sandy loam	2.40	32.20	7+	3.30	72.20	4+	.80	164.20	Tr.	6.50	79.20	8+
Montezuma silty clay loam	7.40	182.00	4+	46.40	222.00	20+	70.40	314.00	22+	38.40	229.00	16+
Hanford coarse sandy loam	1.85	21.00	8+	1.95	61.00	3+	−.15	153.00	.....	3.85	68.00	5+
Olympic loam	3.60	40.60	8+	6.00	80.60	7+	4.40	172.60	2+	4.00	87.60	4+
Oakley sand	3.00	26.60	11+	6.40	66.60	9+	.....	158.60	.....	1.30	73.60	1+
Tejunga stony sand	.....	.....	.....	3.10	.....	.....	1.40	.....	.....	35.00	.....	.....
Kimball fine sandy loam	2.40	9.80	24+	8.00	49.80	16+	5.00	141.80	3+	18.00	56.80	31+
Aiken loam	6.00	50.40	11+	7.00	90.40	7+	20.00	182.40	10+	14.20	97.40	14+
Mendocino loam	3.00	21.00	14+	5.20	61.00	8+	16.00	153.00	10+	7.50	68.00	11+
Holland fine sandy loam	4.00	39.20	10+	10.00	79.20	12+	.50	171.20	Tr.	15.60	86.20	18+
Corona gravelly sandy loam	5.10	54.60	9+	13.80	94.60	14+	58.40	186.60	31+	28.40	101.60	27+
Corona clay loam	3.80	50.40	7+	5.00	90.40	5+	20.00	182.40	10+	14.00	97.40	14+
Yolo gravelly loam	4.00	47.60	8+	7.00	87.60	7+	32.00	179.60	17+	15.80	94.60	16+
Rincon loam	2.80	39.20	7+	3.20	79.20	4+	4.00	171.20	2+	3.00	86.20	3+
Antioch silty clay loam	3.80	35.00	10+	7.80	75.00	10+	26.30	167.00	15+	14.80	82.00	18+
Hanford silty clay loam	1.50	28.00	5+	5.00	68.00	7+	2.10	160.00	1+	2.80	75.00	3+
Placentia clay	2.00	42.00	4+	8.00	82.00	9+	12.00	174.00	6+	14.60	89.00	16+
Sierra sandy loam	4.80	25.20	19+	5.20	65.20	7+	.70	157.20	.....	13.20	72.20	18+
Holland loam	2.40	28.00	8+	3.00	68.00	4+	.....	160.00	.....	9.20	75.00	12+

Owing to the very low total nitrogen content of the Riverside area soils, the relative figures for nitrate transformation given in Table V, Group I, are, if wholly expected, exceedingly large in many instances. Thus, there are six soils, or 11 per cent of the whole number studied, which nitrify more than 20 per cent of the total nitrogen present and 24, or 46 per cent of all the soils, which transform more than 10 per cent of the total amount of nitrogen present into nitrate. On the relative basis, therefore, the Riverside area soils are far superior in nitrifying power to the Bay area soils, but not so in relation to the Pasadena soils; and when compared with the foreign, consisting very largely of humid soils, the Riverside soils are much inferior even on the relative basis.

The results obtained with the soils of the Riverside area employing sulphate of ammonia are perhaps the most striking of all thus far studied. Thus, on the absolute basis there are but 6 soils, or a little over 11 per cent of the whole number tested, which yielded less nitrate (see Table V, Group II) with the combined nitrogen of the soil and of the sulphate of ammonia present than from the former alone. It will be recalled that the corresponding figures for the foregoing series were as follows: Foreign soils, 87 per cent; Bay area soils, 16 per cent; and Pasadena area soils, 21 per cent. In other words, it would appear that the more distinctly arid a soil's character is the more likelihood there is of its being favorably affected by sulphate of ammonia, or to put it otherwise, to have its nitrifying flora stimulated to greater activity. It will be noted that the 6 soils of the Riverside area which were unfavorably affected as to nitrifying power by the sulphate of ammonia are all either sandy, coarse sandy, or gravelly soils. The actual amounts of nitrate produced in many of the soils of this series under the influence of sulphate of ammonia are very large—for example, there are 5 soils which produce more than 40 mgm. of nitrate nitrogen under the conditions of the experiment and 2 other soils which produce more than 20 mgm. of nitrate nitrogen. There are 18 soils in the area, or more than 33 per cent of the whole number studied, which produce more than 10 mgm. of nitrate nitrogen, and 1 soil which produced as much as 63.92 mgm. of nitrate nitrogen. It will be remembered, however, that even this record is surpassed by one of the Pasadena area soils with sulphate of ammonia and that much larger absolute productions of nitrate nitrogen are accomplished with other forms of nitrogen in a number of instances by the foreign soils.

Partly as a result of the high absolute quantities of nitrate produced by soils in the Riverside area and partly owing to the relatively small quantity of total nitrogen present, the percentages given in the last column of Table V, Group II, make a very good showing. Thus, there are 10 soils, or about 18 per cent of the number tested, which transform in every case more than 20 per cent of the total nitrogen present into

nitrate, and 23 soils, or about 43 per cent of the whole number in this area, which nitrify 10 per cent or more of the nitrogen present. When compared with 66 per cent of the soils with such a record among the foreign group with the soil nitrogen alone, it still seems clear that the arid soils are inferior as nitrifying media. Nevertheless one remarkable figure must not be lost sight of among the relative data of Table V, Group II—that is, the 94 per cent transformation of the total nitrogen present into nitrate by the Tejunga fine sand. This means an almost complete nitrification of both soil nitrogen and sulphate of ammonia nitrogen added in one month under the conditions noted.

In the case of dried-blood nitrogen, the Riverside area soils again behave typically. Fifty per cent of all the soils produce in the absolute, as reference to Table V, Groups III and IV, will show, less nitrate from dried blood plus soil nitrogen than from the latter alone. In the Riverside area, however, even more markedly than in the two preceding California areas, there is a considerable number of soils producing large quantities of nitrates from soil plus dried-blood nitrogen. Two points of difference are noted between the Riverside area soils on the one hand and the two groups just mentioned on the other. There are more soils of the class just described in the Riverside area soils than in the Bay area or Pasadena area soils, and very few of them contain nearly as much as 0.1 per cent of total nitrogen. Besides, the absolute quantities of nitrate produced are in four or five cases exceptionally high. It must be noted, however, that in only one case does the nitrification of dried blood exceed that of the soil nitrogen when the soil is stony, sandy, or gravelly and contains little loam or clay. Even that one exception shows but feeble powers of nitrification. In the other cases the soils vary from fine sandy loams with large internal surface to clay loams and clays with larger internal surface. Likewise, it will be noted that in the cases of the 3 soils with more than 0.1 per cent total nitrogen every one made a very good showing in the nitrification of dried-blood nitrogen. It will further be observed that of the 12 soils producing more than 25 mgm. of nitrate nitrogen in this series only one contained less than 0.04 per cent of total nitrogen.

On the relative basis it follows that the Riverside area soils must surpass the Bay area soils in efficiency in the dried-blood series and that they must equal the Pasadena area soils, but they do not do either with respect to the foreign soils. For example, five soils in the group now under consideration transform more than 20 per cent of the blood plus soil nitrogen into nitrate, and six more transform more than 15 per cent of the total nitrogen present in that manner. This is a record only slightly behind that of the Pasadena area soils, but as far behind that of the foreign soils as it is ahead of the Bay area soils. So far as maximum transformation is concerned, however, the Tejunga fine sandy loam in the Riverside area surpasses any soil in the Pasadena area by nitrifying

53 per cent of the total nitrogen of soil and dried blood under the conditions of the experiment. In comparison with the foreign soils as regards dried blood, the Riverside soils must be regarded in the same light as the Pasadena soils, which will be shown more fully later.

Much the same situation as exists in the cottonseed-meal series of the Pasadena area soils is to be found in the Riverside area soils (see Table V, Group IV). There are two principal differences between them. One is that there are only 11 per cent of the Riverside soils, as against 21 per cent of the Pasadena soils, which produce less nitrate in the absolute from cottonseed meal plus soil nitrogen than from the latter alone. The other is that, on the whole, more vigorous nitrification of cottonseed-meal nitrogen occurs in the Riverside than in the Pasadena soils. The latter superiority is based mainly on the fact that more than 17 per cent of all the soils in the Riverside area transform more than 30 per cent of the total nitrogen present into nitrate, whereas the corresponding figure for the Pasadena area is 13 per cent. It may be added also in connection with the preceding that the highest percentage transformation of cottonseed meal plus soil nitrogen found anywhere among the California soil series studied occurs in the Riverside area soil known as the Hanford loam, the record being 66 per cent. On the whole, therefore, the Riverside area soils are the most efficient of any in the nitrification of cottonseed meal plus soil nitrogen. This result is further strengthened by the fact that nearly 70 per cent of all the soils present produce 10 mgm. or more of nitrate nitrogen in this series, as shown in Table V, Group IV. It is clear also that in this group there is further evidence of the definite relationship of degree of aridity in climate to its effect on the nitrifying power of soils for a given form of nitrogen.

THE UKIAH AREA SOILS

Table VI gives the results obtained in our experiments with the Ukiah area soils which were carried out in a manner similar to those described for the other series. Of the Ukiah series, 10 soils, or over 35 per cent of the whole number, contain more than 0.1 per cent of nitrogen. This is 9 per cent in excess of the corresponding figure for the Bay area, which ranks highest in the areas studied. Of the 10 soils just mentioned, 6 contain more than 0.14 per cent of nitrogen, a marked contrast to the corresponding number for the Bay area, which is 1. Nevertheless, while among all the California soil series here studied the Ukiah area stands easily first with respect to the number of soils containing more than 0.1 per cent of total nitrogen, it still falls short more than 26 per cent of equaling the record in the same regard attained by the foreign soils. That, as compared with the other California series, the Ukiah area soils receive the place to which theoretically they should be entitled on the basis of total nitrogen content is also indicated in Table VI. Thus,

it is clear that the Ukiah area should stand first among the California series here studied. This is so because it receives more rain in a longer rainy season and is not subjected to the extremely high tenperatures and other conditions favorable to loss of nitrogen which exist in the more arid areas. There are only three soils in the Ukiah area, or about 10 per cent of the whole number, which contain less than 0.05 per cent of total nitrogen. Two of these approach that point rather closely and the other contains nearly 0.03 per cent of nitrogen and is the only soil which is seriously deficient in nitrogen in the whole area. The 10 per cent value just given, when compared with corresponding values for other California areas, again supports the relationship drawn above between climate and soil nitrogen content and which for the first time is being properly emphasized.

TABLE VI.—*Nitrification in Ukiah area soil types*

Name of type.	Soil nitrogen (Group I).			Soil nitrogen and sulphate of ammonia (Group II).			Soil nitrogen and dried blood (Group III).			Soil nitrogen and cottonseed meal (Group IV).		
	Nitrate produced	Total nitrate present in soil.	Nitrogen nitrified.	Nitrate produced	Total nitrogen present in soil.	Nitrogen nitrified.	Nitrate produced	Total nitrogen present in soil.	Nitrogen nitrified.	Nitrate produced	Total nitrate present in soil.	Nitrogen nitrified.
	Mgm.	*Mgm.*	*P. ct.*	*Mgm.*	*Mgm.*	*P. ct.*	*Mgm.*	*Mgm.*	*P. ct.*	*Mgm.*	*Mgm.*	*P. ct.*
Ukiah gravelly loam	0.10	156.80	Tr.	—0.40	196.80	.....	0.60	288.80	Tr.	0.50	203.80	Tr.
Vichy fine sandy loam	.02	29.40	Tr.	— .28	69.40	.....	.12	161.40	Tr.	.52	76.40	Tr.
Russian silt loam	1.42	91.00	1+	2.42	131.00	1+	1.82	223.00	Tr.	1.82	138.00	1+
Pinole gravelly loam	2.94	77.00	3+	3.64	117.00	3+	— .06	209.00	.....	3.54	124.00	2+
Finn gravelly loam	.30	70.00	Tr.	.44	110.60	Tr.	1.90	202.00	Tr.	.20	117.00	Tr.
Orr loam	4.79	75.60	6+	15.79	115.60	13+	6.29	207.60	3+	2.19	122.60	1+
Large gravelly loam	2.47	203.00	1+	4.37	243.00	1+	18.97	335.00	5+	8.77	350.00	3+
Russian silty clay loam	5.50	147.00	3+	7.50	187.00	4+	28.50	279.00	10+	12.00	194.00	6+
Russian silt loam	2.08	140.00	1+	5.58	180.00	3+	29.58	272.00	10+	8.58	187.00	4+
Largo silty clay	3.63	152.60	2+	6.93	192.60	3+	20.93	284.60	7+	9.53	199.60	4+
Largo loam	6.10	163.80	3+	12.00	203.80	5+	23.60	295.80	7+	13.00	210.80	6+
Sanel loam	.48	58.80	Tr.	.28	98.80	Tr.	— .02	190.80	.....	.07	105.80	.....
Guidiville sandy loam	3.59	42.00	8+	8.39	82.00	10+	— .41	174.00	.....	14.79	89.00	16+
Tehama loam	.03	49.00	Tr.	— .12	89.00	.....	.98	181.00	Tr.	.36	96.00	Tr.
Russian fine sandy loam	.85	53.20	1+	8.35	93.20	8+	8.35	185.20	4+	8.35	100.20	8+
Diablo clay	2.39	63.00	3+	13.89	103.00	13+	11.89	195.00	6+	21.49	110.00	14+
Finn loam	1.42	61.60	2+	1.32	101.60	1+	— .08	193.60	.....	.72	108.60	Tr.
Dublin clay	3.52	147.00	2+	5.82	187.00	3+	23.92	279.00	8+	10.32	194.00	5+
Russian loam	6.45	120.40	5+	10.95	160.40	6+	— .05	252.40	.....	5.15	107.40	3+
Largo silt loam	7.00	135.80	5+	10.80	175.80	6+	4.30	267.80	1+	4.00	182.80	2+
Mendocino loam	2.69	61.60	4+	3.99	101.60	3+	— .01	193.60	.....	.01	108.60	.....
Tehama gravelly loam	1.00	67.20	1+	1.20	107.20	1+	6.60	199.20	3+	.32	114.20	Tr.
Finn gravelly clay loam	1.24	75.60	1+	.28	115.60	Tr.	1.64	207.60	Tr.	1.04	122.60	Tr.
Pinole loam	3.00	54.60	5+	2.40	94.60	2+	.....	186.60	.....	.68	101.60	Tr.
Diablo loam	3.30	85.40	3+	2.90	125.40	2+	.02	217.40	.....	2.58	132.40	1+
Orr clay loam	5.10	112.00	4+	13.70	152.00	9+	39.70	244.00	16+	19.70	159.00	12+
Pinole sandy loam	2.72	85.40	3+	5.62	125.40	4+	— .08	217.40	.....	9.02	132.40	6+
Mendocino gravelly loam	5.46	95.20	5+	15.66	135.20	1+	26.66	227.20	11+	11.86	142.20	8+

With reference to the absolute amounts of nitrate produced from soil nitrogen, it will be seen that the Ukiah soils are distinctly superior to the Bay area soils. Thus, 6 soils in the Ukiah area produce more than 5 mgm. of nitrate nitrogen, as against only 1 in even a larger total number of soils in the Bay series. Moreover, 1 of the 6 soils under discussion reaches a nitrate production equivalent to 7 mgm. Two soils in the

Ukiah series produce almost no nitrates, but no soil loses nitrates during the period of incubation. The average nitrate production is 2.84 mgm. in the Ukiah series and 2.09 mgm. in the Bay area series. The data for the percentage transformation of nitrogen into nitrates in the Ukiah series are also correspondingly larger than those of the Bay area, as is the case with the absolute data. Thus, an 8 per cent maximum transformation is attained in the Ukiah series, as against one of 6 per cent in the Bay area series, and 5 soils besides transform more than 5 per cent of the nitrogen present into nitrate, as against 4 such in the Bay area.

Table VI, Group II, helps to emphasize again the several points made in the foregoing discussion with respect to the behavior of sulphate of ammonia in the Bay area soils. Of the total number of soils in the Ukiah area, 8, or about 28 per cent, produce less nitrate from sulphate of ammonia plus soil nitrogen than from the latter alone. The corresponding figure for the Bay area is 20 per cent. From these facts, it appears that parallelism between degree of aridity of climate and the nitrifying power of soils for different forms of nitrogen is more firmly supported than ever. Thus, the Ukiah area soils as a class having more nitrogen and greater internal surface act more nearly like the humid soils than any of the other California series here studied, even though they are still far removed from the humid soils in that direction. Just as sulphate of ammonia stimulates nitrification in the Bay area soils, so it it does in commensurate degree in the Ukiah area soils. As the average absolute nitrate production is higher from soil nitrogen alone in the Ukiah as against the Bay area group of soils so it is with respect to the sulphate-of-ammonia series of the two soil groups. The maximum transformation of nitrogen into nitrate is also a little higher in the sulphate-of-ammonia series with the Ukiah soils, it being 13 per cent in the case of two soils, as against 11 per cent, which was the corresponding figure in the Bay area soils. On the other hand, there are about equal numbers of soils in the two areas (4 or 5) which transform more than 9 per cent of the total nitrogen present in this series into nitrate. The other soils are all considerably more feeble in nitrification. The average nitrogen transformation on the relative basis is only slightly greater in the Ukiah than in the Bay area soils with sulphate of ammonia as the nitrifiable material.

Only 35 per cent of the soils in the Ukiah area produce less nitrate from combined soil and dried-blood nitrogen than from the former alone (see Table VI, Group III). This is in sharp contrast to the Bay area soils, for which the corresponding figure is 50 per cent, and with the Pasadena area, for which the corresponding value is 63 per cent. All of these, moreover, are in sharp contrast to the corresponding value for the foreign soils, which is 20 per cent. It will be noted next that very large nitrate productions are accomplished in the dried-blood series. Such quantities are in all cases much in excess of those produced by the same

soils in the sulphate-of-ammonia or the soil-nitrogen series. Thus, 8 soils in a total of 28 produce more than 20 mgm. of nitrate nitrogen under the conditions of the experiment. Allowing for one or two exceptional soils, the break between the high nitrate-producing soils and the rest in the blood series is very abrupt. As against the 8 soils just referred to in the Ukiah series, there are but 3 in the Bay area series of a corresponding class. In general, nitrification of dried-blood nitrogen proceeds very much better in the Ukiah series than in the Bay area soils. In fact, the discrepancies in nitrifying powers between the two soil groups are better exemplified with dried blood than with any other form of nitrogen. With one exception, all the soils in the dried-blood series which produce more than 20 mgm. of nitrates contain considerably more than 0.1 per cent of nitrogen, and are all possessed of large internal surface. The one exception mentioned is Mendocino gravelly loam, which contains very nearly 0.1 per cent of nitrogen and has a large internal surface besides. Owing to the higher nitrogen content in many of the soils of the Ukiah area than in corresponding soils of the Bay area, the relative figures for the two areas using dried-blood nitrogen as the nitrifiable material do not differ as much as the absolute figures. Nevertheless the relative values are again distinctly in favor of the Ukiah area soils.

A study of Table VI, Group IV, brings us to a consideration of cottonseed-meal nitrogen in its relations to the soils of the Ukiah area. As a result of such consideration we find that 40 per cent of the soils concerned produce less nitrate from cottonseed meal plus soil nitrogen than from the latter alone in every case. This is a behavior with respect to cottonseed-meal nitrogen very similar to that evinced by the foreign soils, the corresponding percentage for which was 37. The latter is obtained even with a few arid and semiarid or otherwise peculiar soils included, as previously pointed out. On the other hand, the corresponding figure for the Bay area soils is 26 per cent, and it is much lower for the other areas. In other words, it would seem that the Ukiah soils not only approach very closely in their behavior to cottonseed meal that of humid soils, but also that the curve in that respect shows a gradual decline with an increase in the aridity of the climate concerned. The maximum absolute production of nitrate is 29.49 mgm. as seen in Table VI, Group IV, accomplished by the Diablo clay. This record is surpassed in two cases in the Bay area series, and nearly equaled in two others.

It may be well to summarize briefly from one or two points of view the results which were obtained in the experiments with the California soils. In a similar manner, therefore, to that employed in Table II for the foreign soils, Table VII gives for California the percentage of soils in each area which transformed more than 10 per cent of the total nitrogen in a given culture into nitrate, giving every form of nitrogen separately.

TABLE VII.—*Percentage of California soils transforming more than 10 per cent of nitrogen present in culture into nitrate*

Form of nitrogen.	Soil area.			
	Riverside.	Pasadena.	Bay.	Ukiah.
Soil nitrogen alone	47	34	0	0
Soil nitrogen plus ammonium sulphate	47	47	6	10
Soil nitrogen plus dried blood	30	28	10	14
Soil nitrogen plus cottonseed meal	70	50	20	10

It appears, therefore, that in the Riverside, Pasadena, and Bay areas the cottonseed-meal nitrogen gives the best results in the largest number of soils. In the Ukiah area cottonseed meal takes second place and divides honors with sulphate of ammonia. Sulphate of ammonia takes second place in the Riverside, Pasadena, and Ukiah area soils, but third in the Bay area soils. The soil nitrogen does, however, contend with it for second place in the Riverside soils. Dried blood is last in both the Pasadena and Riverside soils, but first in the Ukiah soils and second in the Bay area soils. Soil nitrogen is either second or third in the Riverside soils, is third in the Pasadena soils, and last in the other two areas.

Table VIII gives relative values on another basis than that employed in Table VII. This latter criterion consists in computing the percentages of soils which produce with every form of nitrogen more than 15 mgm. of nitrate in the foreign soils and is based on the amounts of total nitrogen present in corresponding quantities in the other soil areas. Thus, the figure is 11 instead of 15 for the Ukiah area, 10 for the Bay and Pasadena areas, and 5 for the Riverside area.

TABLE VIII.—*Percentages of soils producing more than 15 mgm. of nitrate in foreign soils with every form of nitrogen*

Form of nitrogen.	Soil area.				
	Riverside.	Pasadena.	Bay.	Ukiah.	Foreign.
Soil nitrogen alone	24	18	0	0	52
Soil nitrogen plus ammonium sulphate	71	71	16	25	25
Soil nitrogen plus dried blood	41	42	30	31	81
Soil nitrogen plus cottonseed meal	75	80	23	21	63

Similar relations appear to hold in this manner of computation as in that previously employed. Some minor differences, however, are apparent. Ammonium sulphate very definitely takes second place in all the California soils except the Bay area. Cottonseed meal is still first in the Riverside and the Pasadena soils, but blood is first in the Ukiah and Bay area soils. The soil nitrogen is fourth in all the California soil areas.

In addition to these observations, it may be remarked that in the last column, in the foreign soils, dried blood stands first, as it does in the Bay and Ukiah areas, and soil nitrogen stands third. Sulphate of ammonia in the foreign soils again takes last place instead of a close second, as in the Riverside and Pasadena areas, and cottonseed meal stands second instead of first.

COMPARISON OF FOREIGN AND CALIFORNIA SOILS

It has been shown that 52 per cent of the foreign soils, which include several arid or semiarid soils, produce more than 15 mgm. of nitrate nitrogen out of the total soil nitrogen present. Neither the Bay nor the Ukiah areas includes any soil of such nitrifying activity. However, it was not expected that they would produce the same number of milligrams of nitrate nitrogen, but merely an amount having an approximately similar ratio to the total nitrogen as that in the foreign soils. While the Riverside and the Pasadena areas, with 24 per cent and 18 per cent, respectively, of soils with an equivalent nitrifying power to that of the foreign soils mentioned, are much more active than those of the other two arid-soil areas just referred to, their records are still far behind those of the foreign soils. These comparative data were arranged as noted on the basis of equivalent quantities of total nitrogen, a basis employed because of the claim which has been made that the quantity of nitrogen rendered available in a soil is always a certain constant proportion of the total nitrogen present in soils. If the latter theory is tenable, arid soils are certainly very much more feeble in the nitrification of soil nitrogen than humid soils. But if the theory above mentioned is incorrect, the data are all the more emphatic as to the considerable disparity (in favor of the humid soils) between the nitrifying power for soil nitrogen of soils of the arid and humid regions.

On the assumption that the stimulating or depressing effect of a certain nitrogenous material on the soil's nitrifying power under laboratory conditions is a justifiable criterion, the percentage of soils in every group which produced less or more nitrate from soil plus fertilizer nitrogen than from soil nitrogen alone have been noted. Table IX has been arranged on the basis of all those calculations.

TABLE IX.—*Percentage of soils in every area which produced less nitrate with fertilizer plus soil nitrogen than from soil nitrogen alone*

Soil.	Source of nitrogen.		
	Sulphate of ammonia and soil.	Dried blood and soil.	Cottonseed meal and soil.
Foreign	88	20	46
Ukiah	28	35	40
Bay	16	43	26
Pasadena	21	63	21
Riverside	11	50	11

It seems clear from Table IX that sulphate of ammonia induces under laboratory conditions a larger yield of nitrate in the large majority of the soils of arid regions than could be produced by those soils with their own nitrogen. The range in the percentage of such soils is not large and varies between 89 per cent in the Riverside area and 72 per cent in the Ukiah area. On the other hand, it is clear also that in the large majority of soils in the foreign group ammonium sulphate has the opposite effect—that is, to depress the nitrifying power of a soil for its own nitrogen. The effects of sulphate of ammonia are thus almost exactly reversed in a comparison of the Riverside and the foreign soils, for example. In the comparison made by Sackett (10) of the nitrifying power of certain Colorado soils (using ammonium sulphate) with certain others from several other States, it will be noted that the foreign soils, with the exception of the California soils, acted as a class like those studied by the writers. Likewise, the Colorado soils are more like the arid soils which were described previously. In other words, the Colorado soils were superior in nitrifying power for sulphate-of-ammonia nitrogen to soils from other States, even not excepting the California soils. It must be remembered, however, that anything more than a general analogy or comparison between the writers' results and Sackett's is not permissible for the following reasons: Sackett used 100 mgm. of ammonium-sulphate nitrogen, while the writers used 40 mgm. in the soil cultures. He inoculated the cultures with a fresh soil suspension in the case of every soil studied, which was equivalent to 5 gm. of soil, while the writers merely employed the soil flora existing in the air-dried soil. Sackett used a six weeks' period of incubation, whereas the writers employed only a four weeks' period. In several other minor respects the conditions of Sackett's experiments were different, among which may be particularly mentioned the method of analysis employed for nitrate determinations.

In the case of dried blood, conditions seem to be almost the reverse of those with ammonium sulphate. The soils of the foreign group which produce less nitrate from dried blood than from their own nitrogen alone are decidedly in the minority, but the reverse is true of the arid soils of California as they become more and more humid in character. Dried blood therefore induces a loss in nitrate-producing power in from 35 to 63 per cent of the soils of the arid region. On the other hand, the same substance affects only 20 per cent of the total number of foreign soils in that manner. Hence, there is a stimulation to nitrification in some soils of the arid region induced by the presence of dried blood in them. The opposite is true with humid soils.

With respect to the stimulating or retarding action on the nitrifying powers of the soils studied, cottonseed meal acts almost exactly like ammonium sulphate in the Pasadena and Riverside areas. The difference between the two materials is, however, much greater in the other two arid-soil groups; but still in both cases the percentage of soils in which apparent losses in nitrifying power are induced is below that of the foreign

group. The latter is none the less almost half the magnitude of the corresponding figure for sulphate of ammonia with the foreign soils.

From all the foregoing considerations it appears evident that different forms of nitrogen exercise widely different effects on different groups of soils. Thus, for example, ammonium sulphate seems to enhance the nitrifying powers of arid soils and to depress those of humid soils. Dried blood seems, in general, to operate in a reverse manner, while cottonseed meal seems to act more like the ammonium sulphate. It will be remembered that conclusions similar to those reached for arid soils were drawn by Lipman and Burgess (7) with respect to another group of arid soils with which they worked. Moreover, Sackett, in the experiments cited, noted that the relationship of the Colorado soils to sulphate of ammonia and to dried blood was the reverse of the relation of the other soils which he studied to those substances. The position of the Colorado soil was similar to that occupied by the California soils with respect to the foreign soils. The apparently mystifying feature of the comparison lies, however, in the fact that the California soils tested were in Sackett's foreign group (10) and, therefore, in his hands gave different results from those obtained by us. This may perhaps be accounted for by the fact that the foreign soils are considered as a whole and are not separated from the California soils, which in reality give much better results than, for example, the eastern soils with sulphate of ammonia.

Table X has been arranged to bring together some of the figures above discussed with respect to the relative powers of soils to nitrify different forms of nitrogen. The first group shows the percentage of soils in each of the areas studied which transformed more than 10 per cent of the total nitrogen present into nitrate in the case of every form of nitrogen employed. The second group shows the percentage of soils in every area which produced a quantity of nitrate equivalent to 15 mgm. in the case of the foreign soils. The equivalent amount for soils other than those of the foreign group was determined by using the same ratio of nitrate to total nitrogen which is employed in the last-named groups of soils, the average total nitrogen content of all soils in a given area being used as a basis.

TABLE X.—*Transformation of nitrogen in various soil areas*

Form of nitrogen.	Percentage of soils which transformed 10 per cent or more of nitrogen into nitrate.					Percentage of soils producing 15 mgm. of nitrate nitrogen in the foreign area and an equivalent quantity based on nitrogen present in other areas.				
	Riverside area.	Pasadena area.	Bay area.	Ukiah area.	Foreign area.	Riverside area.	Pasadena area.	Bay area.	Ukiah area.	Foreign area.
Soil nitrogen only	47	34	0	0	68	24	18	0	0	52
Soil nitrogen and ammonium sulphate	47	47	6	10	23	71	71	16	25	25
Soil nitrogen and dried blood	30	28	10	14	47	41	42	30	31	81
Soil nitrogen and cottonseed meal	70	60	20	10	45	75	80	23	21	63

By the different arrangement of the data in Tables VIII to X a reversal of indications in minor ways has perhaps been brought about. But, in general, certain differences of a marked character in the nitrifying powers of humid and arid soils are obvious. Thus, by whatever method compared, the soil nitrogen of humid soils seems to become nitrified more readily than that of arid soils. Likewise, the opposite is true of sulphate-of-ammonia and cottonseed-meal nitrogen and their effects on the nitrification of soil nitrogen, and, as pointed out, the difference may amount to veritable inverse relationships. On the other hand, the opposite of the effects noted for the forms of nitrogen just discussed is true in general for dried-blood nitrogen. The most marked differences are, of course, evident between the foreign soils on the one hand and the Pasadena and Riverside soils on the other, because the latter are more distinctly arid in character than the Ukiah and Bay soils.

REVIEW OF RESULTS

Since the results obtained by the writers are very striking and offer the first direct evidence, so far as they are aware, of the differences between the nitrifying powers of humid and arid soils, it is essential that their findings be viewed critically. The first question which arises is that of the representative nature of the samples of soil employed with respect to the different climatic regions. The four soil areas chosen to represent arid soils in California may be taken as representative because they exemplify as nearly as possible interior valley and coast conditions in both southern and northern California. Since more than twice as much rainfall is normally received by the Bay and Ukiah areas as that received by the Riverside and Pasadena areas, these soils, all of which are none the less arid, should be considered as representative of average conditions in the State. If, however, it is desired to apply the term "arid" only to regions receiving less than 20 inches of rain a year, it is necessary to consider only the Riverside and Pasadena soils. So far as soil nitrogen and nitrification are concerned, the Riverside area will fairly represent a large, if not the largest, part of the San Joaquin Valley, a small part of the Sacramento Valley, the Coachella and Imperial Valleys, and nearly all of the Mojave and the Colorado Desert regions besides. The Pasadena and the Bay areas may be taken as nearly representative of the coast valley conditions from San Francisco to San Diego, the first being only in behavior more typical of the southern and the second of the northern valleys. The Ukiah area will partly represent a large portion of the northern half of Sacramento Valley and much of the coast region above San Francisco. In general, therefore, the four soil areas are fairly representative of California conditions, and in particular may serve, as above indicated, to represent the typically arid conditions of the State if only a certain area or areas be chosen.

In regard to the humid soils, the situation is by no means as satisfactory. As already indicated, the soil samples from the other States were sent by Experiment Station officers and may therefore, in many instances at least, have been chosen from exceptionally well-managed fields. On the other hand, it would not be fair so assume that the land of every State Experiment Station is the best to be had in the State. It is unlikely that the samples here studied would represent anything more than average conditions of the Eastern States. It must be added, of course, that when the soils of individual States of the humid group are considered, most of them may be found either very deficient or very excellent in respect to nitrifying power. Such of the Eastern States, however, as contain soils throughout of a low nitrifying power are decidedly in the minority. It is therefore gratifying to be able to point to the relatively low nitrifying power of the Sassafras loam from New Jersey, as given in Table I, and to show in Table XI the nitrifying powers, similarly determined, of a number of other New Jersey soil types for comparison. It was fortunate that these samples of soil were made available from an exhibit sent to the Panama Pacific Exposition by the New Jersey Experiment Station.

TABLE XI.—*Comparative nitrifying power of soil types from New Jersey*

Name of type.	Nitrate produced.	Total soil nitrogen present.	Soil nitrogen nitrified.
	Mgm.	*Mgm.*	*Per cent.*
Hoosic gravelly loam	4.30	149.80	2+
Norfolk sand	.10	15.40	.....
Colbington sandy loam	3.75	103.60	3+
Dover loam	5.30	121.80	4+
Dutchess loam	.30	81.20	.....
Sassafras loam	2.40	131.60	1+
Penn loam	4.10	99.40	4+
Light sandy loam	2.50	96.60	2+
Do	3.40	74.20	4+

Since the samples described in Table XI were kept in a dry condition in sacks for considerably over a year, it is possible that the soils may have lost to a relatively slight degree their powers to nitrify their own supply of nitrogen, and the figures obtained might be regarded as a little low on that account. This effect on the New Jersey soils of drying could not have been very great, as the evidence of the other soils would show. It is therefore seen that of nine types of New Jersey soils studied, not one has the power to change much more than 4 per cent of the total nitrogen present into nitrate, and the samples described in Table I transformed only a little more than 6 per cent of the soil nitrogen into nitrates. It is interesting to note that the last-named sample, while classified as a Sassafras loam, is very different in total nitrogen content

and in nitrifying power from the sample of the same name described in Table XI. This question of variation in any one type is now being investigated.

In general, therefore, it appears possible that some States may contain very few good nitrifying soils, others very few poor nitrifying soils, and still others contain a fair proportion of both. If this possibility is allowed, then the samples described in this paper as the foreign soils must approach closely the average conditions of humid soils, despite the criticisms which are above suggested.

The next question is that of the influence of the seasonal variation in the nitrifying activity of soils on the validity of nitrification data, and particularly of those above presented. As pointed out in the introductory part of this paper, there are now in the writers' possession many data on the monthly variation in the nitrifying powers of several different soil types. These data, which cover a period of 1½ years of monthly tests, indicate even more strikingly than former results in this regard the great variability to which such determinations are subject. Hence, the low nitrifying powers of the Bay and Ukiah area soils which were gathered from November to December, 1914, may be regarded as due to the depressing effect of the conditions of the late fall, particularly as regards a lack of moisture. It is also realized that the much greater relative activity of the soils of the Pasadena and Riverside areas may in part be accounted for by the collection of the samples in June and July, when conditions were more favorable to nitrification. The humid soils were collected in various parts of the year, but the bulk of them arrived at Berkeley between September 15, 1914, and January 1, 1915, and soon thereafter were tested. If anything, therefore, the seasonal effects should have caused the samples from the humid soils to be somewhat depressed in nitrifying efficiency, but they show themselves superior as a class to the arid soils in the nitrification of soil nitrogen. In view of this fact and of the opportunity offered for the comparison of a variety of seasonal effects in both arid and humid soils, great significance can not be attached to the influence of the seasonal variations, which are characteristic of nitrification determinations, on the validity of the results.

The quantity of dried blood employed in the cultures in which that material was tested will next be considered. It has recently been pointed out (5) for dried blood that the nitrification of small quantities may proceed normally in certain soils, as has also previously been shown to be true for calcium cyanamid and for goat manure (7), whereas large quantities would not only permit no nitrification but would actually induce losses of nitrate from the soil. In comparative studies like those described previously the absolute values obtained are not significant except as side issues, provided all classes of soils tested are treated alike.

Such like treatment has, of course, been accorded all the soils. It would therefore seem that the figures are illuminating if not exactly for the use of dried blood in general, at least for 1 per cent of dried blood as the nitrifiable material. Of course, the possibility still remains that with 0.05 per cent or 0.1 per cent of blood, instead of the 1 per cent employed in the cultures, the results in the blood series may have favored the arid and not the humid soils, as they did in these experiments. That, however, is quite unlikely, since it is unreasonable to suppose that smaller quantities of dried blood would have been nitrified with less vigor in the humid soils than the large quantity employed. Except, therefore, as it might have changed absolute values, the procedure in the use of dried blood appears to be no factor in the comparison here made between the powers of humid and of arid soils to nitrify dried-blood nitrogen.

The depression of nitrification in most arid soils by 1 per cent of blood in nitrification experiments was briefly explained by the senior author (6, 7) on the following hypothesis: Ammonification of dried blood proceeds very rapidly. Ammonia is poisonous to the nitrifying organism. If a soil has a large internal surface for adsorption, as, for example, in the presence of large quantities of decaying organic matter, in organic colloids, or a similar material, the ammonia produced by the process of ammonification is quickly adsorbed and removed from harmful action on the nitrifying bacteria. If the contrary is true of the internal surface of soils, such as would obtain in sands poor in humus or in closely packed soils of finer texture, the ammonia given off in the ammonification of dried blood would be toxic to the nitrifying bacteria. This would take place by a direct toxic effect and also by the depressing effect on nitrification of large quantities of soluble organic matter in the soil solution introduced through the solvent effects of ammonia on the dried blood. Very few arid soils have been found incapable of nitrifying 1 per cent of blood which did not also yield a very dark soil solution, indicating the active dissolution of the organic matter present. Very few such soils, moreover, have been noted which do not give off a strong odor of ammonia during the period of incubation. That both dissolved organic matter in the medium and free ammonia deter or inhibit the process of nitrification by pure cultures has been proved for solution cultures by Winogradsky's experiments (14). That the same is true for soils in the presence of mixed cultures has not been known, however, until now. Since the hypothesis was first formulated, the writers have carried out experiments, not possible of description here, which clearly point to the highly toxic nature of relatively small quantities of ammonia to the nitrification of dried blood in soils which otherwise transform the nitrogen of that material into nitrates without difficulty. It is further gratifying to note that Hutchinson (4) has arrived at a similar result to that which the writers have obtained on the toxicity of ammonia to the process of nitrification.

If the hypothesis briefly explained is correct, the difference in the behavior of the humid and arid soils toward the nitrification of dried-blood nitrogen is at once explicable, since the amounts of organic and inorganic colloids are usually much larger in the humid than in the arid soils and would act toward the ammonia produced from dried blood as above explained. Even if it should prove desirable to use smaller quantities of dried blood in cultures to determine its availability in arid soils, the method used heretofore may serve as an excellent means for the comparison of groups of soils and as an index to the soil's internal surface and its status with reference to colloid content.

In connection with this discussion it is cogent to refer to the results obtained by Sackett (10), showing that Colorado soils are superior in nitrifying power to 22 soils from localities outside of that State. These results would seem to imply that for some reason Colorado soils are in general superior in nitrifying efficiency to other soils. A comparison of Sackett's data with the writers', however, does not bear out such an implication when the nitrification of the soil's own nitrogen and not that of fertilizer nitrogen is considered. Thus, for example, in the Pasadena area out of 33 soils about 45 per cent produced 7 mgm. or more of nitrate in 100 gm. of soil in a month's incubation period. Of the 23 Colorado soils tested by Sackett only 21 per cent of such soils were found; yet the average total nitrogen content of the Pasadena soils is probably below that of the Colorado soils and Sackett's incubation period was six weeks and the writers' only four weeks. When a relative instead of an absolute basis of comparison is used, similar results are obtained in other California areas. But the humid soils outstrip the Colorado soils even farther than the Pasadena soils and show clearly a very superior nitrifying power as a class for the soil's own nitrogen to that possessed by the Colorado soils.

So far as the nitrification of sulphate-of-ammonia nitrogen is concerned, the Colorado soils do seem to be superior to other soils if the soils chosen by Sackett are fairly representative of Colorado soils. They are, however, to be considered as a class only slightly superior to the Riverside and Pasadena soils when it is considered that we employed a much shorter period of incubation, much less sulphate of ammonia, and did not inoculate our soils with fresh infusions. In fact, it appears now that an equal comparison of the Riverside or Pasadena soils with the representative Colorado soils would probably show them to be very similar in respect to nitrifying powers for sulphate of ammonia. While it would be difficult to establish any fixed criterion, it would seem, however, that the soil's own nitrogen would for all ordinary purposes best subserve the purposes of soil fertility. If such a criterion is adopted, then the Colorado soils as well as the arid soils of California can not only be said not to be superior in nitrifying power to the humid soils but it is barely possible that they are appreciably inferior in that respect.

Attention must be called to the fact that the classification for purposes of discussion of the Pasadena area as a coast valley is not done with any idea of so classifying it permanently. It is merely done to emphasize its closeness to the sea and its greater rainfall and attendant factors which affect many of the soils in that area so as to make them more characteristic of coast than of interior valley conditions under which the Pasadena area would normally be classed.

Several other minor points of interest with respect to the data which have been discussed deserve consideration here. Most of the soils above studied from the South Atlantic States are deficient in nitrogen, and in that respect resemble, for example, the truly arid soils of the Riverside area. Likewise, with respect to the nitrification of nitrogen in dried blood and cottonseed meal, but particularly the former, the South Atlantic soils behave more like the truly arid soils. Their behavior could therefore be accounted for on the hypothesis explaining the behavior of the truly arid soils toward dried-blood nitrogen, taking the low nitrogen content of the soils as an index of the organic matter present and, hence, indirectly of the total internal surface. That, however, aside from the total nitrogen considerations and their indications that climate exerts additional effects on the soil's nitrifying power, is exemplified by the fact that the South Atlantic soils, while behaving toward dried blood and partly toward cottonseed meal like arid soils, stand, with respect to soil nitrogen and sulphate of ammonia, in the position of the truly humid soils. The latter is more easily explicable on the basis of soil acidity with respect to sulphate of ammonia and that of superior moisture conditions with respect to the soil nitrogen. It will be noted that two soils which did not nitrify their own nitrogen well are the Kentucky and Louisiana soils. The first was collected in December and the second in March, which would probably account for the relative inactivity of the nitrifying organisms. With the exception of the last two soils, it will be noted in Table I, Group I, that the South Atlantic soils are far superior in their nitrifying powers for soil nitrogen to the soils of the Riverside area.

It will be noted that the total nitrogen content of soils in connection especially with the nitrification of dried-blood nitrogen has several times been emphasized. This is done to indicate, in a general way, the likelihood of the presence of certain quantities of organic colloids in the soil on the assumption that the soil's nitrogen content bears a more or less intimate relation to the quantity of organic matter present. The latter, moreover, is considered as an indication in its turn of the amount of internal surface contributed to the soil from that source in addition to that present there by virtue of the surfaces of inorganic constituents, including sand, silt, and clay.

SUMMARY

A study was made of the nitrifying powers, under incubator conditions, of about 40 humid and about 150 arid soils. The soil was used as a medium and the forms of nitrogen employed were soil nitrogen, sulphate of ammonia plus soil nitrogen, dried blood plus soil nitrogen, and cottonseed meal plus soil nitrogen. The humid soils were obtained from the different State and Territorial Experiment Stations, one type of surface soil from each one being used in these experiments. The arid soils employed represented the soil types of four typical soil-survey areas in California. The results obtained appear to justify the follow-lowing statements:

(1) The conclusion appears ineluctable that the nitrifying powers of soils of the arid region are no more intense than those of the humid region. This denies Hilgard's (3) teaching to the contrary and confirms the statement of Stewart (11), which was based on more indirect and less extensive evidence.

(2) While indications are not by any means positive now, it is possible that the data of the writers justify the further conclusion that the nitrifying powers of humid soils are greater than those of arid soils. If such a conclusion could be drawn, it would have to be based merely on the nitrification of soil nitrogen and dried-blood nitrogen. The former being the natural source of supply of most of the available nitrogen obtained by crops, it should really be regarded as the most valuable basis for forming a judgment.

(3) Arid soils, on the other hand, nitrify the nitrogen of sulphate of ammonia and cottonseed meal with much greater vigor than do the humid soils. A reversal of efficiency is manifest between the two groups of soils as regards sulphate of ammonia and cottonseed meal, on the one hand, and dried blood and soil nitrogen, on the other.

(4) These results not only throw new light on the question of nitrification in soils of different climatic regions but also tend to confirm the earlier findings of the writers and others on the important relation of climate to soil properties (9).

(5) The foregoing considerations apply to the two groups in general and not to parts of such groups in particular. For example, the Bay and Ukiah soils do not nitrify soil nitrogen as efficiently as the more arid Pasadena and Riverside soils. This may, however, be accounted for by the seasons at which the collection of the soils was made and by the physical condition in which the Bay and Ukiah soils were received.

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IMMOBILITY OF IRON IN THE PLANT

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INTRODUCTION

Work at the Porto Rico Experiment Station on the assimilation of iron by certain plants, including rice (*Oryza sativa*), has afforded results which seem to show that iron is relatively immobile in the plant after it has once been transported to the leaves. In respect to mobility in the plant iron would thus be similar to silicon and calcium and different from nitrogen, phosphorus, potassium, and magnesium, which are generally considered mobile.

These observations on the immobility of iron are chiefly concerned with the nontransference of iron from leaf to leaf under conditions where the plant was insufficiently supplied with iron. That the mobile mineral elements and nitrogen are translocated from leaf to leaf under such conditions seems proved by Schimper (8)[1] as well as by observations on the growth of plants in media lacking one of these elements. The translocation of nitrogen, potassium, and phosphorus from old leaves and stems to the fruiting parts has, of course, been well established by ash analyses of plants during maturation and by direct experiments (6, p. 585–586). This, however, is not different in principle from the translocation of these elements from old to new leaves, as the constituents must in this case also pass from the old leaf into the stem.

The various facts which seem to point to iron being relatively immobile in the plant are given below.

OBSERVATIONS ON RICE GROWN IN NUTRIENT SOLUTIONS LACKING IRON

Rice grown in nutrient solutions without iron is quite different in appearance from rice grown without nitrogen or phosphorus. In iron-free solutions the leaves of the plants commence to die at the top rather than at the base of the plant. The newer leaves that are formed are almost pure white, very thin, and generally wither before the old leaves. The phenomena in rice grown in absolutely iron-free solutions are not so marked as in plants grown for a time with iron and then transferred to an iron-free solution; since either the amount of iron in the seed does not suffice for the needs of the first leaves or it is incompletely translocated, so that even the first two or three leaves formed are yellowish green in color.

[1] Reference is made by number to "Literature cited," p. 87.

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A lot of rice was grown for 13 days in a nutrient solution well supplied with iron and then transferred for 13 days to a solution identical except for the absence of iron. The leaves formed during growth in the complete nutrient solution were dark green, while the leaves that formed in the 13 days after change to the iron-free solution were yellowish green to creamy-white, the old leaves retaining their dark-green color during this change. The chlorosis or lack of green in the newer leaves was obviously associated with a lack of iron and due to a nontransference of iron from the green lower leaves.

Similar phenomena in regard to the appearance of chlorosis were observed by Molisch (4, p. 92) on growing *Cucurbita pepo*, *Helianthus annuus*, *Zea mays*, etc., in iron-free solutions.

The appearance of rice grown in nitrogen or phosphorus-free solutions was quite distinct from that of plants grown in iron-free solutions; the leaves commenced to die from the base upwards, and new leaves were continually formed at the top of the plant. Here there evidently was a translocation of nitrogen or phosphorus from the old leaves to the new, as growth continued after all material in the seed had been exhausted, and new tissue could not have been formed without these elements.

OBSERVATIONS ON PLANTS AFFECTED WITH LIME-INDUCED CHLOROSIS

Experiments at this station showed that the chlorosis of some plants on strongly calcareous soils was due in part at least to lack of iron; at all events appropriate treatment with iron salts cured the chlorosis. Phenomena similar to that observed in rice grown in iron-free solutions were observed with rice and pineapples (*Ananas sativus*), grown in calcareous soils. Rice when not immediately affected with chlorosis showed the chlorosis in the new leaves, even though the old leaves were green. The new leaves formed came out yellowish green to creamy-white and withered completely, the plants dying from the top down, while the lower leaves remained sound and green. Pineapples behaved similarly, in that the chlorosis appeared first in the new leaves, although frequently the lower leaves followed the new ones in becoming chlorotic, until eventually the whole plant became chlorotic.

If iron were mobile in the plant after once being transported to the leaves, evidently the phenomena would have been different. Iron would have been translocated from the old to the new leaves, the scene of most active growth, and the old leaves would have withered or become chlorotic first.

BRUSHING WITH IRON SALTS THE LEAVES OF PLANTS LACKING IRON

Rice plants grown in certain nutrient solutions with a lack of available iron developed chlorosis and were brushed with a 0.2 to 0.4 per cent solution of ferrous sulphate. In the course of this treatment the tips of leaves just emerging from the stalk were brushed. As these leaves grew

out, the part that had been brushed was a normal green, while the lower, unbrushed part of the leaf was strongly chlorotic and remained so until treated with iron. This would hardly have been the case if the iron were mobile in the leaf tissue. Of course, if a great excess of iron had penetrated the epidermis, it might have been translocated to other parts of the leaf.

The inefficiency of spraying the leaves with iron salts, as a means of curing the chlorosis of pineapples or grapevines, is probably partially due to the immobility of iron in the leaves.[1] With pineapples this treatment completely restored the green color to the leaves treated, but new leaves formed after the treatment were chlorotic.

EVIDENCE FROM ASH ANALYSES

Ash analyses of old, young, and withered leaves generally support the view that iron once conducted to the leaf is immobile, although they by no means afford proof. It should be borne in mind, however, in judging many of the old ash analyses that the determination of the relatively small amounts of iron by precipitation as ferric phosphate is not particularly accurate. Also the accuracy of many results where iron was not the chief element sought may well have been affected by contamination. The writers have found the colorimetric potassium-sulphocyanate method, either in usual form or as modified by Stokes and Cain (9), more accurate than the usual method.

Czapek in his compilation states that old leaves as a rule contain more iron than young ones (1, p. 800). The work of Fliche and Grandeau on the composition of leaves of different trees at various stages of growth supports this (3, p. 487). Analyses made at the Porto Rico Experiment Station of leaves from 1-year-old rough-lemon trees (*Citrus limonum*) show the lower or older leaves to be higher in iron than the young leaves. The lower and upper leaves of plants from four different soils were sampled. The percentages of iron in the dry substance are given in Table I.

TABLE I.—*Percentage of iron in young and in old rough-lemon leaves*

Soil No.	Age of leaves.	Iron (Fe_2O_3) in dry substance.
		Per cent.
I	Young	0.017
I	Old	.044
II	Young	.021
II	Old	.039
III	Young	.012
III	Old	.025
IV	Young	.014
IV	Old	.023

[1] It is significant that with certain kinds of chlorosis of grapevines, treatment of cut stems with the iron salts (method of Rassiguier) has proved more efficacious than spraying the foliage.

With respect to the accumulation in old leaves, iron is similar to silicon and calcium, which also seem immobile in the plant when once transported to the leaves. Young leaves are generally relatively higher in the mobile elements than old leaves. This parallelism, however, really affords little proof, as the relative amount of the different ash constituents present in young and old leaves is probably governed more by the function than the mobility of the elements. Also the accumulation of iron in the old leaves of plants well supplied with iron may merely show that a functioning leaf has a continual need of iron. As iron is in some way associated with the formation of chlorophyll and as chlorophyll is apparently undergoing a continual formation and destruction under the influence of light (2, p. 193; 5) and enzyms (10, p. 746), one can conceive of a physiological necessity for an accumulation of iron in old leaves.

The most that can be said concerning the evidence of ash analyses is that the results are such as one would expect if iron were immobile after being located in the leaf.

DISCUSSION OF RESULTS

The only references to the mobility of iron in the plant which the authors have found in the literature are a discussion by Sachs (7) and a statement by Pfeffer that "in a starved green plant, as well as in a fungus, the iron and potassium may be removed from the older dying organs and transferred to the younger growing parts so that the growth may not immediately cease" (6, p. 417). No data or reference are given in support of this statement. While the movement of potassium under such conditions is generally recognized, the same can hardly be said of iron.

Lack of information on the movement of iron is partially due to the fact that iron has ordinarily been considered of so little interest in plant nutrition as to be disregarded in ash analyses. Also, as already pointed out, the usual method of determining iron in plant analyses is probably not sufficiently accurate to show significant changes.

Sachs, in his interesting discussion of the chlorosis of various plants grown under garden conditions (on a calcareous soil), points out the apparent slowness with which iron moves in plants (7).

From the data presented it is not intended to assert that the non-translocation of iron from leaves is an absolutely general rule for all plants, since the foregoing observations were based chiefly on rice and pineapples.

Various observations on rice and pineapples grown with insufficient iron seem to show that iron after once being transported to the leaves is immobile.

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